DOCUMENT RESUME

ED 305 225 SE 050 403

AUTHOR	Stewart, Denis, Comp.
TITLE	Better Science: Making It Relevant to Young People. Curriculum Guide 3.
INSTITUTION	School Curriculum Development Committee, London (England).; Secondary Science Curriculum Review, London (England).
SPONS AGENCY	Association for Science Education, Cambridge (England).
REPORT NO	ISBN-0-435-54821-2
PUB DATE	87
NOTE	50p.; For the curriculum review see SE 050 400; for other curriculum guides in this series see SE 050 401-412.
AVAILABLE FROM	Heinemann Educational Books, Inc., Halley Court, Jordan Hill, Oxford OX2 8EJ, United Kingdom ($44.40 English pounds per set).
PUB TYPE	Reports - Descriptive (141) -- Viewpoints (120) -- Guides - Non-Classroom Use (055)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Curriculum Development; *Educational Improvement; Elementary Secondary Education; Foreign Countries; Instructional Development; Instructional Improvement; *Relevance (Education); *Science Curriculum; Science Departments; Science Education; Science Instruction; Science Teachers; *Secondary School Science
IDENTIFIERS	*United Kingdom

ABSTRACT

This is the third in a series of 12 curriculum guides. These publications are recommendations which the committee made for a broad and balanced education program in science for young people. The main theme of this guide is that science education which young people experience during their period of compulsory schooling needs to be characterized by relevancy and applicability. The primary focus is on consumers and their perceptions of the "goods." Section one explains the meaning of school science relevancy, school science applicability, and reasons for promoting certain brands of relevance and applicability. The next three sections consider ways and means of making school science relevant to students. These are exemplified by a selection of material from Secondary Science Curriculum Review (SSCR) working groups. Section five deals with the nature of technology, its place in the school curriculum, and its relationship to science in the curriculum. Section six presents an essay entitled "Biotechnology in the School Curriculum" (David Ingleby). A summary of recommendations are listed in section seven. References are included. (RT)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED305225

SECONDARY SCIENCE CURRICULUM REVIEW

SSCR

BETTER SCIENCE: Making it relevant to young people

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

X This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

Eluned Harries

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Curriculum Guides

SECONDARY SCIENCE CURRICULUM REVIEW

SSCR

BETTER SCIENCE:

Making it relevant to young people

Curriculum Guide 3

Compiled by Denis Stewart

Heinemann Educational Books/Association for Science Education
for the School Curriculum Development Committee

The Secondary Science Curriculum Review has run from 1981–1986 (Phases 1 and 2), with a dissemination phase (Phase 3) from 1986–1989.

The Review operates under the aegis of the School Curriculum Development Committee and is supported by the Association for Science Education. In addition, it receives or has received support from the Department of Education and Science, local education authorities, the Schools Council (Phase 1), the Northern Ireland Council for Educational Development (Phase 2), the Health Education Council (Phase 2), industry (particularly British Petroleum), the Department of Trade and Industry, and the Independent Broadcasting Authority.

Acknowledgements

The ideas presented in this Guide are not only the result of the work of SSCR groups. Their production has also relied on considerable discussion in, and on the collective wisdom of, the SSCR Central Team:

Beverley Bell (CLIS Project Coordinator 1984–85), Di Bentley (Research and Development Officer, Health and Science Education 1983–86), Paula Bower (Information Officer 1984–86), Christine Ditchfield (Southern Regional Project Officer), Dave Ebbutt (Evaluation Officer 1983–86), Kate Ellington (North West Regional Project Leader 1983–86), John Heaney (Midlands Regional Project Officer), Joseph Hornsby (North Regional Project Officer), Ruth Jarman (Northern Ireland Regional Project Leader 1983–84), Jeff Kirkham (Director from 1986; Director Designate 1985–86), Anna Larter (Project Administrator), Mick Michell (Director 1985-86; Deputy Director 1982–85), Val Oldham (CLIS Project Coordinator 1985–86), Denis Stewart (Regional Project Officer Wales & West Midlands from 1986; Northern Ireland Regional Project Leader 1984–86), Jeff Thompson (Chairman, SSCR Steering Committee), Mike Watts (Anglia Regional Project Leader 1983–86), Dick West (Director 1981–85), Cathy Wilson (ASE/SSCR Liaison Officer).

The compiler is very grateful to David Ingleby and John Holman for their written contributions, and to the following people who have so generously given of their time in order to read and comment on various drafts of the document: Terry Allsop, Di Barton, Paul Black, David Brierley, John Brown, Martin Brown, Mike Byrne, Barbara Godding, George Goldby, Boyd Gunnell, Maggie Hannon, Geoffrey Harrison, David Ingleby, Edwyn James, Roger Lock, Bob McCormick, Brian McGarvey, Carroll Nicholl, Jim Sage and Paul Wymer.

Finally, and not of least importance, warm thanks are due to Catherine McAfee for her diligent help at each stage in the preparation of the manuscript.

The publishers would like to thank the following for permission to use extracts and diagrams:
The Assessment of Performance Unit and the Controller of Her Majesty's Stationery Office for a diagram from *Science in Schools. Age 15. Report No. 2*: Leicestershire Education Authority for material from *Science as a Process: Encouraging the scientific activity of children*; A.J. Williams for pupil material from *Man and the Environment*; P. Black, G. Harrison and the Nuffield-Chelsea Curriculum Trust for diagrams from *In Place of Confusion: Technology and science in the school curriculum*; H. Graham for an extract from *Medical Technology: A science teaching module*.

Heinemann Educational Books Ltd
22 Bedford Square, London WC1B 3HH

LONDON EDINBURGH MELBOURNE AUCKLAND
SINGAPORE KUALA LUMPUR NEW DELHI IBADAN
NAIROBI JOHANNESBURG PORTSMOUTH (NH) KINGSTON

The Association for Science Education,
College Lane, Hatfield, Herts

ISBN 0 435 54821 2
© SCDC Publications 1987
First published 1987

Typeset by Artext Ltd, London
Printed and bound in Great Britain by
Scotprint Ltd, Musselburgh

Contents

Introduction 1
Through the eyes of a consumer 1
What this booklet is about 1

SECTION ONE **Making school science relevant and applicable: a rationale** 2
Introduction 2
Saying what we mean 2
Relevant to what, or to whom? 2
Applicable by whom, and for what? 3
Reasons for making school science more relevant and applicable 3
Learning and using science ideas 5
The argument so far 6
A wider cultural perpective 6

SECTION TWO **Ways and means: involve pupils in the processes of science** 7
Two types of approach 7
Science as problem-solving 7
What sorts of problems? 8
When should problem-solving be used in science lessons? 10
How does problem-solving relate to practical work? 11
Why should problem-solving be used in science lessons? 13

SECTION THREE **Ways and means: vary the contexts** 16
Contextualising school science 16
Some examples from SSCR materials 17
Contexts, problems and active involvement in learning 20
Some examples of non-SSCR work 21

SECTION FOUR **Ways and means: create interest and cultivate curiosity** 23
Broadening the appeal of secondary science studies 23
Palatable science for all? 23
The humanness of science 24
The accessibility of science 24
Teaching science and teaching about science 24

SECTION FIVE **Technology and science in the school curriculum** 25
Setting the scene 25
What is technology and how does it relate to science? 26
Why should technology feature in the school curriculum? 28
How ought technology to feature in the school curriculum? 28
Current practice in school technology education 32
Developing technological awareness and capability through science studies 34

SECTION SIX **Biotechnology in the school curriculum** 36
Why should biotechnology studies be in the school curriculum? 36
Fitting biotechnology into the curriculum 36
In conclusion... 39

SECTION SEVEN **Summary of recommendations** 40

References 41

Foreword

This is the third in a collection of twelve Curriculum Guides from the Secondary Science Curriculum Review, published jointly by Heinemann Educational Books and the Association for Science Education.

A Directory of Resources and a book, *Better Science: Making it happen*, which tries to set the Review's recommendations in the context of the whole school, will appear at the same time as the Guides. These will, when taken with earlier and forthcoming SSCR publications, including those from local groups, constitute the recommendations which the Review is making towards a broad and balanced science education for all the young people in our schools. The series title 'Better Science' is thus both apposite and self-explanatory. It is hoped that the current phase of the Review (1986–89) will achieve successful implementation of the recommendations.

But what is the status of these new publications apart from reflecting the formal approval and support of our major sponsors, the School Curriculum Development Committee and the Association for Science Education? From what sources have the recommendations within them emanated? Those readers unfamiliar with the history of the SSCR will find it explained within the Guides; but most will be aware that it set out as a project which tried fully to involve the practising teacher in the development of solutions to the problem of science for all. Thus, although the Guides have been compiled principally by the Central Team of the Review, they draw on the work of thousands of teachers in working groups over the past four years. Although the work of many of the groups is referred to in the Guides, it is not possible to refer to it all. In the *Directory of Resources* readers will find details of what many of these groups have produced. The writing of these Guides, however, would not have been possible without the groups' existence and the Review Central Team hopes that the content of the guides truly reflects their work. Thus the pronoun 'we', used within them, often reflects the view, gleaned over five years of consultation, of the practising teachers involved with the Review. On other occasions it can represent the views of the SSCR as constituted by the Central Team and Steering Committee and it is hoped that particular usage will be apparent from the context.

Jeff Kirkham, Mick Michell, Jeff Thompson,
Dick West (SSCR Curriculum Guide Editors)

Introduction

Through the eyes of a consumer

Jennifer Martin is sixteen and feeling good. Since yesterday she has been celebrating her success in several GCSE courses, including one in science. Encouraged by her achievement she is giving some thought – more serious than before the results came out – to the possibility of tackling some A levels from September on. But which subjects should she pick? She is pleased with her double GCSE award in science, though it certainly wasn't the best of the bunch.

But then Jennifer has always found science interesting – even enjoyable a lot of the time. Her sister, Joanne, who went to the same school and left with some quite good O Levels about six or seven years ago, used to complain about how much she disliked science, especially physics. She never could see the point of it all. Unlike Joanne, Jennifer found she actually enjoyed the physics – and chemistry – parts of the science course she did in fourth and fifth years. Not that it was easy; far from it! But the teachers always seemed to be able to connect it with everyday things, or with questions about the environment, ethics and such like – things that she, and many of her classmates,thought were important.

Then there were all the times when she could work with other people in the class, trying to sort out her own ideas about light and seeing, chemical reactions, how plants feed,and so on. It was good to be able to talk about problems, in small groups, and to think of ways of testing ideas. The teacher who took Jennifer's class for the physics and chemistry was usually a great help, even though he didn't claim to have all the answers. Anyway, things weren't always as straightforward as the books made out. Nevertheless, learning and trying to understand scientific explanations somehow helped to make more sense of the world. She found history, geography and religious studies were like that too. They were just different ways of looking at the world.

Some of the experiences that Jennifer remembers most vividly were those times when they worked on projects. One that was especially good involved trying to produce cauliflowers (of all things!) by a method calling cloning. The group Jennifer was in did some work on the design and construction of a cabinet in which plantlets could be grown under controlled conditions. One of the CDT teachers helped out with this and Jennifer enjoyed being able to make use of some of the talents she had developed in CDT classes. Later on they studied the effects that using this method of producing cauliflowers might have on jobs in the surrounding countryside. A geography teacher was involved with their work at this stage. Thinking about the prospect of doing A levels in one or two sciences and possibly history, Jennifer wonders whether there will be opportunities to do more of this sort of project work in the sixth form.

What this booklet is about

Though fictitious this brief sketch of one consumer's perceptions of the school science 'product' reflects aspects of existing realities, which many young people and science teachers will recognise. It has to be said, however, that the positive attitudes evident in Jennifer's thinking are more a reflection of some of the aspirations and wishful *afterthoughts* of ex-students of school science than of their testimonies to actual personal experience (**0.1**). Doubtless such testimonies could be recorded but the general impression of many of those involved in secondary science education is that these would be the exception rather the rule.

In recent years many teachers and others have become increasingly disturbed, in spite of improvements that have been made, by several features of school science including:

- the questionable relevance to most youngsters of the contexts in which much science is taught;
- the over-emphasis in many science curricula on scientific knowledge and concepts at the expense of scientific processes and enquiry skills, and of learning about science as a human activity;
- the tendency in much school science to emphasise the accumulation of scientific facts and concepts rather than learning how to deploy these in solving a variety of problems.

The central theme of this document is that the science education which young people experience during their period of compulsory schooling needs to be characterised, to a significantly greater extent than is generally the case at present, by **relevance** and **applicability**. In elaborating on this theme the primary focus will be on the 'consumers', and their perceptions of the 'goods'.

In Section 1 we set out what we mean by

'relevance in school science' and 'applicable school science' and give our reasons for promoting particular brands of relevance and applicability. One of the points made is that relevance to children's existing ideas is important in their learning of new ideas in science.

In the next three sections we consider ways and means of actually making school science relevant to young people, and exemplify these, for the most part, by a selection of material from SSCR working groups. Reference is also made to non-SSCR work, such as that being carried out by the Science and Technology in Society (SATIS) project. In Section 2 we look at ways of involving young people in the processes of science by providing them with opportunities to solve scientific problems. The section includes discussion of the relationship between problem-solving and practical work. Section 3 is about using contexts to which youngsters can relate and Section 4 considers the need to broaden the appeal of school science and to cultivate young people's curiosity in science.

Much of the work being done to make school science more relevant to youngsters and more applicable by them involves technological aspects of science and technological problem-solving exercises. In Section 5 the nature of technology, its place in the school curriculum and its relationship to science in the curriculum are discussed.

Section 6 consists of an essay by a teacher who has been very much involved in SSCR activity during the past few years. His subject–*Biotechnology in the School Curriculum*, is one of the most substantial strands in the Review's science curriculum development work. Finally we present a summary of our recommendations in Section 7.

SECTION ONE

Making school science relevant and applicable: a rationale

Introduction

That secondary science education needs to be made more **relevant** and **applicable** than it is, at present, is our basic contention. We consider how this might be achieved in Sections 2–4. But first, in this section, we explain just what we mean by relevant and applicable, and why we believe that relevance and applicability are essential characteristics of 'science for all'.

Saying what we mean

Throughout this document we shall use the word relevance in the sense of relatedness or fitness, and the word applicability to denote both the practical *and* the cognitive utility of science. In our view, science is relevant partly, but not exclusively, because it is applicable; relevance includes applicability, but is not equivalent to it.

Relevant to what, or to whom?

> *Science education should be presented and assessed in a way that allows the pupils to see its direct relevance to their lives...* (**1.1**, Para. 46)

Varieties of relevance

There are several ways in which educational experiences are regarded as relevant. Thus it is argued that the science curriculum should be *socially* relevant, in the sense that it helps to prepare young people for participation in a democratic society. Another example is the call from many employers for schools to adopt a more *industrially* relevant curriculum; education in schools is to be related and responsive to what Jamieson (**1.2**) calls 'the supposed needs of employers' in order that 'industry might ultimately be more productive'.

Certainly we agree that the curriculum in general, or the science curriculum in particular, should be *industrially* and *vocationally* relevant in that, for example, it lays the groundwork for employment. However, educationally it is of more fundamental importance that, as the author of one recent article puts it, the curriculum should be relevant, first and foremost to 'the growing understanding, experience and interest of the individual'. (**1.3**)

> **Above all else, school science ought to be relevant to the individual young person.**

Children's grasp of what is *personally* relevant to them may well include perceptions of social

relevance, industrial relevance and so on, but it transcends these. For most youngsters it is important that what they are being encouraged to learn in school can be *fitted* into their mental world or *related* in meaningful ways to their interests, and aspirations and to the real world as *they* experience it. (See, for example, **1.4**). Of course each young person's experiences, aspirations and interests change as time passes; their views about what is relevant may also change. To take just one example, it is not uncommon for older pupils to become more concerned about the relation of schoolwork to their developing vocational aspirations. If the curriculum appears to such pupils to be irrelevant then clearly something is amiss – either with the planning or with the delivery of their school experiences. This does *not* mean that the school curriculum should adopt strong orientations towards particular vocations each of which will appeal only to particular young people. (See Section 6). Rather the onus is on schools to provide a good general education, through science and other subjects, which is demonstrably appropriate as a foundation for all kinds of employment – and, indeed, for coping with the consequences of possible unemployment – as well as for further studies.

Ways in which school science can be personally relevant

Science education can be directly relevant to students in a number of respects:

- it can impinge on their thinking about themselves and their physical and social environment;
- it can focus on objects and phenomena that are part of youngsters' everyday experience and which capture their interests;
- it can connect with other aspects of their experience of secondary schooling, and with hobbies and leisure activities.

Applicable by whom, and for what?

> *Pupils ... should become accustomed to using their science in different circumstances inside and outside schools so that they are able to apply their knowledge and skills to whatever problem is being considered* (**1.1,** para. 55)

Coming to see the direct relevance of science to our lives involves becoming aware of ways in which science, through its methods and ideas as well as through its applications, profoundly affects us and the way we think of ourselves. But it involves more than this. One way or another we human beings are concerned about utility. We like to feel that we can make use of our acquired knowledge and skills. Likewise, for young people in school, finding that science could be **of use to them** can contribute to their sense of its personal relevance. So, students need to discover, through personal experience, that it isn't only scientists and technologists who use scientific knowledge and scientific ways of doing things but that *they can do so too*. They should have opportunities to learn about the *applicability* of science (what it can be to them) as well as the *applications* of science (what it is used for by others).

> **Students should have opportunities to practise the application of science to matters which interest them, as well as to learn about its application by others.**

Science, both as knowledge and concepts and as processes, can be applied *by pupils* in at least three ways:

- as they learn to investigate phenomena and seek to understand the world;
- as they attempt to solve practical or technological problems;
- as they endeavour to formulate views on some of the science-related social and ethical issues that confront them as members of contemporary society.

There is one important point to notice here: the applicability of science encompasses using science to solve **practical** problems, but extends beyond this into its application for **cognitive** purposes. (See Section 2: *What sorts of problems?*)

Reasons for making school science more relevant and applicable

> *We are expecting that they will be interested in everything that we do ... However a lot of what we do doesn't relate very directly to outside experiences ... so that they can't see in a number of things where it is really fitting in for them.* (A science teacher; quoted in **1.4**)

So what's the problem?

Thus far we have expounded our belief that *all youngsters ought to be finding that science education is personally relevant and useful*. Probably most people would agree that science is indeed relevant, in a variety of respects, to all of us (see **1.5**). The problem is that, all too often, pupils in secondary schools do not see science like this. The sixth-form student (quoted in **0.1**) who declared:

> *I've found no use for my science except to help my younger brother with his homework now he is in the fourth year*

may not represent the norm of young people's attitudes to their experience of science in schools.

Nevertheless, judging from this recent study of sixth-formers' views of their science education up to the age of sixteen, it does seem that many youngsters feel that relevance to their thinking about the world and to everyday life did not feature enough in the science they experienced in school. In one student's words, school science needed to 'connect with the real world' (**0.1**). As a recent editorial expressed it:

> *... the isolation of science from the realities of everyday life ... often leaves the youngsters disenchanted with what seems to them meaningless learning* (**1.6**).

There are, of course, some who do seem to get more from their secondary science than an examination certificate. As one sixth-former put it (**0.1**):

> *... science helps you to understand the world about you and helps you to understand what they're talking about on a news item ...*

However, such positive views of school science would appear to be the exception rather the rule. For many secondary school pupils, perhaps the majority, it seems that science teaching needs to 'make science ... relevant to pupils' present and future lives' (**1.7**).

Why is personal relevance important?

There are two connected reasons for trying to make school science more relevant to youngsters.

Emotional involvement

Perceiving personal relevance in a science topic is likely to engender in pupils curiosity, interest, enjoyment, enthusiasm and a sense of satisfaction.

Studying science should be an interesting, enjoyable and satisfying experience. When science lessons appear to children to lack relevance, interest in science and enthusiasm for learning wane (**1.4**). That is not to imply that learning science should be all plain sailing. Clearly it cannot be so. Youngsters doing science will always face difficulties and are bound to feel frustrated, disappointed or subdued at times. Learning, as well as living, is like that. Learning should also bring experiences which delight and give a sense of personal fulfilment; it should never amount to being no more than boring drudgery. Some pupils may accept such drudgery in the hope that the effort they put in will bear fruit in the form of examination success. Others may simply decide that science has nothing worthwhile to offer, and choose other alternatives.

In his helpful discussion of factors that may affect children's motivation for learning science, Head (**1.8**) summarises some of the research into pupils' attitudes to school science and indicates (**1.8**, p.35) that 'it can be argued that the more students meet science the less they like it'. Why? There would seem to be several possible causes of this apparent trend. Adolescents may become increasingly disenchanted with school science because they have a dehumanised image of science and scientists, or because they have the impression that science is simply a collection of right answers that are arrived at by the correct application of somewhat impersonal, mechanical procedures.

Thus it may be that some youngsters are 'turned off' conventional science education as they progress through school because 'science rarely seem to address their concern for personal identify and ideals' (**1.8**, p.84).

For others a preoccupation, during fourth and fifth year, with cramming for examinations seems to coincide with a diminution in their enjoyment of science lessons. The reflections of a sixth-former (**0.1**), illustrates this last point:

> *... probably the third year was sort of fun; you could enjoy it; it was the one subject you could hold together. But when you got to fourth and fifth year, it was a matter of having a subject for your examinations ... So it made you that you didn't enjoy it, because you probably had to take it because it was a job you wanted. You couldn't get all excited about it.*

Surely science ought to be something which all young people can be excited about whether they are 7, 11 or 15.

Giving meaning and purpose to their learning

Students are more likely to learn new ideas and skills if they see some point and personal significance in doing so.

If students are able relate a topic to what motivates *them*, to *their* experiences and *their* own ideas, they will probably be more inclined to take an interest and more willing to apply themselves to the process of making sense of new experiences later.

One of the examples cited by Papert (quoted in **1.9**), to illustrate his argument that affective considerations are important in learning, concerns a ten year old called Bill. Bill seemed to his teachers to be incapable of learning multiplication tables, and yet he had

> *extensive knowledge of popular and folk songs, which he had no difficulty in remembering ... (and he could) ... recount reference numbers, prices and dates for thousands of records. The*

difference between what he 'could' and 'could not' learn did not depend on the content of the learning, but on his relationship to it.

This illustrates the point that, for learning to be successful, the knowledge and concepts learned need to be significant for the person concerned. In other words relevance to the learner's experiences and ideas can have an important influence on learning outcomes.

In view of the widespread concern about the efficacy of current approaches to teaching scientific concept and theories, it is worth considering more closely issues which relate to this aspect of our rationale for relevance in school science.

Learning and using science ideas

If students are to be helped to change their existing ideas towards the currently accepted school science ideas, then their existing (and alternative) ideas may need to be given attention in class. (**1.10**, p.2)

In recent years awareness has grown in the science education communities of a number of countries that many young people find it difficult to understand and use some of the fundamental concepts of science, even after several years of intensive exposure to school science.

Why should this be so? There is little doubt that part of the problem is the overloading of science syllabuses with conceptual (and factual) content. Hence one important reason for reducing the content of 11–16 science is to allow room for pupils to become more familiar with the concepts they do meet **(Better Science: Choosing content).** A closer look at the problem indicates very clearly that its resolution will also depend, to a considerable extent, on proper attention being given to the issues of relevance and applicability.

In the UK one of the most significant findings to emerge from surveys undertaken on behalf of the Assessment of Performance Unit (APU) is that **pupils find it difficult to apply science concepts.** Performance in this respect is particularly low in questions which are set in contexts other than those commonly encountered in science lessons (**1.11**, pp. 184-5; **1.12**; pp. 38-40, and **1.13**). For example, in their discussion of pupils' responses to a number of survey questions related to the topic 'Air' the APU team have this to say (**1.11**, p.182):

It is interesting to note that the questions which were answered by the smallest proportion of pupils were those which called for a scientific interpretation of very familiar situations such as plant growth. This result is a reminder that in teaching science we need to focus not only on the component ideas in any topic, but to give pupils opportunities to relate them to commonplace phenomena as well as to the more contrived 'scientific' situations found in the school laboratory.

Even students who seem to have satisfactorily learnt scientific ideas for examination purposes find it difficult to apply them to everyday phenomena.

There are at least two lessons we can learn from findings like these. In the first place, if a scientific idea is to be seen by youngsters as useful for understanding them, then the phenomena that teachers use to illustrate the idea must include some which are familiar to youngsters and of interest in their own right. Secondly, since having a thorough understanding of a concept or theory includes being able to use it, students of science should be provided with opportunities to apply the new ideas they are being asked to learn in a variety of situations.

Children's learning in science could be assisted by encouraging them to link the ideas they are being taught with commonplace objects and events and to apply new ideas in a wide range of situations.

In addition, children's existing ideas and beliefs are also important. Not only does the conceptual content of school science need to be connected with and applied to pupils' everyday experiences, but also **it is essential for pupils to have opportunities to relate that which they observe, read or discuss in science lessons to their own prior knowledge.**

Among those who argue for more account to be taken of children's intuitive ideas in science teaching are the members of the Children's Learning in Science Project (CLISP) team. The argument is rooted in the belief that learning is a process in which all of us are constantly engaged and which involves the construction of meanings.

Learning may be viewed, not as a transmission exercise of passing facts and concepts from an expert to a novice, but as a constructive process in which the learners are viewed as being active in constructing and accepting ideas for themselves and teachers as enablers and facilitators of this process. (**1.10**)

According to this **constructivist view of learning** what we derive from a learning experience is affected in part by the knowledge and beliefs that we bring to that experience. Moreover learning which is meaningful entails being willing to accept new ideas as well as being able to construct them.

Ultimately, therefore, the responsibility for learning (for constructing a personal understanding of a phenomenon) rests with the learner.

Students need to be encouraged to make sense for themselves of what they experience. Unfortunately youngsters' attempts to grapple with problems and make things meaningful for themselves are easily, and all too often, short-circuited in science lessons. Pupils are frequently diverted

> *by the quest for the right answer to the teacher's question or the textbook problem, or to getting the 'right readings' in the laboratory exercise* (**1.14**).

Where their results differ from those the teacher expects they soon learn that they need to record the 'correct result' of an observation exercise or an experiment rather than that which they have found themselves. (For example see: **1.14**, and Chapter 6 in **1.15**).

> *This type of occurrence must lead many secondary school students to separate the knowledge they learn in science lessons from their everyday world. For them school science is knowledge which may be accepted within the context of the contrived situations in classrooms and laboratories, but they may not believe in it or use it in out-of-school experiences.* (**1.14**)

If this diagnosis is accepted then it is not surprising to find that, when youngsters are confronted with problems set in everyday contexts, they often revert to their intuitive ideas – even though they may appear to have grasped and given assent to taught ideas.

Many examples of such failure to use accepted ideas (that is, ideas accepted by contemporary scientists and/or by the teacher) have been documented by the CLISP team and by other researchers. (See, for example, **1.15–1.17**.) The CLISP work indicates that, despite the attention given to ideas about the particulate nature of matter, energy and plant nutrition in secondary science courses only a minority of students learn, and use with confidence, the accepted ideas (**1.18–1.20**).

Why should youngsters be encouraged to apply science?

Given all that has been said already our answers to this question can be stated quite briefly. Youngsters ought to have opportunities to apply scientific ideas and processes for at least three reasons:

- in order that their sense of its personal relevance is enhanced;
- in order to help them to learn through using the new ideas they encounter in science lessons;
- in order to increase their confidence in their ability to do science.

The argument so far

Greater enjoyment and personal satisfaction are benefits that should flow to the 'consumers' from a more personally relevant science education. They are not, however, the only benefits. Making school science more relevant and applicable should also help students:

- to become scientifically more capable and self-confident;
- to learn scientific concepts and theories more easily;
- to increase their awareness of the personal and social significance of science.

Broadening the appeal of school science education by making it more relevant to young people goes hand in hand with developing students' scientific capability, awareness, and understanding.

A wider cultural perspective

Clearly our main concern is with improving the quality of school science for the individual pupils; at the same time the changes in emphasis which we are advocating may also lead to a higher level of scientific literacy and capability in society. One author has expressed the wider cultural purpose of making science education more relevant and applicable in this way (**1.8**, p.86):

> *If appreciation of the utility and relevance of science is achieved in school then it should carry into adult life and help bridge the rift between the two cultures, for those not opting for a science based career as much as anyone else.*

In a short article on *Physics, Relevance and Understanding*, Terry (**1.21**) has compared pupils' school physics experience to 'a trip down the motorway at close to the speed limit with no opportunity to examine the scenery en route'. Most pupils, he says, are 'not there for the ride itself'. Instead they are 'relieved to get off at the first opportunity'. There can be little doubt that such a metaphor applies to more than the physics component of secondary science. Making science compulsory for everyone up to the age of sixteen will not, by itself, solve the problems. One thing we must do is to change and vary the route, and the mode of transport, so that following the secondary science curriculum becomes more like a brisk, refreshing walk along a series of scenic paths!

SECTION TWO

Ways and means: involve pupils in the processes of science

In teaching science we should be concerned both with introducing students to the important body of scientific knowledge, that they might understand and enjoy it, and also with familiarising students with the way a problem-solving scientist works, that they too might develop such habits and use them in their own lives. (**2.1**, p.32).

Two types of approach

In this section we begin to examine the work of SSCR local working groups – and in Section 3 of some related non-SSCR materials – as a means of illustrating what can be done to make school science personally relevant and applicable for young people.

Science can be said to have at least three dimensions: its **methods** (the processes of science), its corpus of **knowledge** (the 'facts', concepts, and principles, usually designated the content of science), and its **contexts.** Schools need to offer a balanced exposure to all three. Much of the effort that is being directed towards improving current provision is aimed at redressing the balance away from excessive emphasis on knowledge so that in science classes more attention is devoted to children *doing science* and *relating science to out-of-school contexts* as well as to academic and laboratory contexts.

Many of the SSCR groups have been working along these lines, developing approaches to science teaching which emphasise the **processes** of science, and the importance of giving youngsters opportunities to engage with these processes; or which give a more prominent place to **everyday contexts** to which youngsters can relate. More often than not the two approaches are interwoven in a single piece of teaching or learning material. One apparently very simple example of this is described in Box 1.

Match of the Day

This is one of a collection of problems related to the applications of science. The problem for pupils is to determine the breaking load of two types of matches. Not only do they have an opportunity to design and carry out an experiment, the pupils are also encouraged to consider social and economic, as well as physical, factors which influence the design of a match.

Box 1 A problem involving 'process' and 'context' (**2.2**, p.15)

Indeed, one of the advantages of using problem-solving in science lessons is that it can provide excellent opportunities for teachers to introduce discussion of the social, environmental, economic and other implications and issues.

In this section we look at involving young people in the processes of science and in Section 3 we look at its contexts.

Science as problem-solving

One way of helping youngsters to see the personal relevance and applicability of school science is to provide them with opportunities to learn to *work as scientists*, investigating phenomena in a systematic way, finding solutions to scientific problems. Approaches to science education which stress the importance of encouraging the scientific activity of children are variously described as 'investigative' (e.g., **2.3**), or 'process-based' (e.g. **2.4** and Box 2) or 'problem-solving'.

The process approach involves providing students with situations in which they can apply and develop science skills. ... Once developed, we think science skills can be used in a wide variety of situations ... the scientific knowledge learned through the approach is important too. ... So a successful process lesson is one in which the students acquire or improve the skills involved; in doing this they will also gain valuable knowledge about the phenomena being investigated.

Box 2 *Encouraging the scientific activity of children* (**2.5**, pp.88–9)

Problem-solving is used most frequently (**2.2**, **2.6**–**2.10**). Indeed problem-solving has become a 'contemporary educational buzz-word' (**2.11**) – and not only in connection with science education. The problem-solving process is freely aired in discussions of curricular areas like home economics, mathematics and health education, but nowhere more so than in relation to technology education (see Section 5).

Problem-solving of the 'finding things out' variety is a fundamental part of doing science. The Assessment of Performance Unit (APU), for example, refers to 'science *as* problem-solving' and conceives of the process of performing an investigation as a 'problem-solving chain' (see **2.12**, p.4, and Fig. 1). Many of those in the SSCR groups which have developed problem-solving activities

have based their work on models of scientific process that are similar to the APU model. For example, the members of an Avon SSCR group, which has devised a collection of problems for use with 11–13 year olds (**2.7**), see the process of solving problems as involving:

1 identifying and analysing the problem;
2 planning, which takes account of limitations (time, resources, their own skills, etc.);
3 collecting information;
4 thinking of a number of alternative solutions;
5 designing and trying out the best ideas;
6 evaluating the outcome(s) and, if need be, modifying the solution;
7 presenting the final outcome(s).

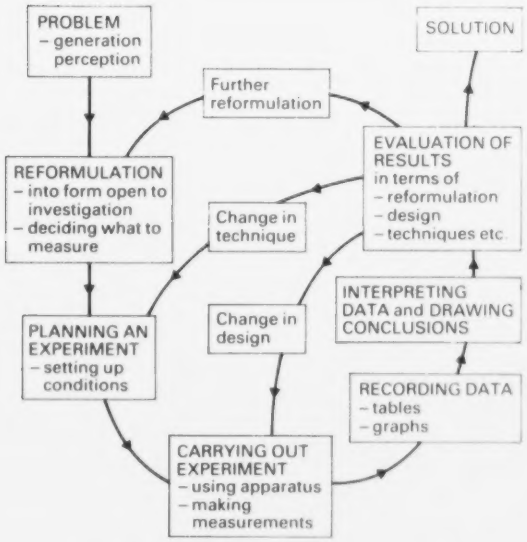


Fig.1 *The problem-solving chain* (**1.11**)

What sorts of problems?

The problems that teachers have been developing and using in science lessons are many and varied and can be classified in a number of ways(**2.2**, p.4; **2.13**.) They usually involve practical work but, as Heaney has pointed out in a recent paper on problem-solving (**2.14**), this is not always or necessarily the case.

> *Problems can be tackled on paper, by discussion in a group or even by an individual just thinking in a disciplined way.*

Some problems can be solved by individuals – others are best tackled by a small group of people working together. The most commonly encountered classification depicts a spectrum of problem types ranging from **closed problems** at one extreme to **open problems** at the other. The extent to which a problem is 'open' is related either to the number of possible routes to a solution, or to the number of solutions that are possible, or to both.

An example of a closed problem is:

- *Given samples of food colourings and a supply of paper and apparatus for chromatography, find out which artificial colourings are present in orange 'ice-pops'* (cf. **2.7**).

Presumably there is one correct solution to the problem; in addition, the number of ways in which the problem may be solved has been effectively limited to one by the manner in which the problem has been posed. If the problem was: 'Find out which artificial colourings are present in orange ice-pops', and especially if it was introduced during a study of, say, food or health which did not follow *immediately* after work on chromatography, it would now be characterised by some degree of openness, at least from the pupils' points of view. Here are two examples of fairly open problems:

- Which is the best material for making egg boxes? (**2.10**, p.21)
- Design and construct a forcemeter with which to compare the effectiveness of different egg box designs and materials in protecting eggs from damage in a fall of one metre (**2.9**).

Nott (**2.11**) makes some good points when he cautions us against assuming that closed means dull, boring and educationally worthless. He goes on to say:

> *This may be the case but ... it is not intrinsically necessary. On the other hand open has become synonymous with exciting, motivating and educationally valuable. This may be the case but it may also be that it is confusing, too difficult and unstructured.*

Alternatively we may categorise problems in school science according to whether their endpoints are **practical** or **cognitive**.

Scientific problems with practical endpoints

These are problems which require pupils to apply what they have learned in science lessons to the achievement of a practical end. Often this sort of problem involves **finding a way of performing a measurement or test or some other practical operation**. 'Testing stickiness', a problem developed for 10–13 year olds by an SSCR group in Northamptonshire nicely illustrates this category. The children are asked to find a way of measuring the stickiness of glycerol. To get them thinking the teacher poses the question, 'What do we mean by 'stickiness'?', and suggests that they might like to reflect on such notions as thickness, tackiness and fluidity as they set about designing an experiment (**2.10**, pp.29-30). In another exercise devised by the

same group, youngsters are presented with the task of finding how much water some plant leaves contain (**2.10**, p28). The problem is deceptively simple, especially where the pupils have not had experience of longer term investigations in science. Other examples are:

- Separate a mixture of sand and sawdust into its components using simple apparatus (**2.15**, p.46).
- Devise an experiment to find the approximate energy content of a peanut (**2.15**, p.50).
- What is the strongest tissue? (**2.9**, p.47)
- Is there a better way of assessing the rate at which cabbage ferments to form sauerkraut than monitoring pH? (cf. **2.16**, p.F17)
- Which type of disposable cup is best for keeping hot drinks hot? (**2.7**)
- How old is a sample of milk? (**2.2**, p.19)

Alternatively, problems which have a practical end point may require students to **find the optimum conditions for a process** or to **design and construct a useful artefact.** In effect the students are being set tasks that are wholly or partly technological (Section 5). It has to be said, however, that the distinction between technological problems and practical scientific problems is not always clear-cut. Take, for example, the search for a plant pigment which performs best as an indicator (**2.9**, p.45); or the task of producing an ink that can be used to write a message, that will not fade too quickly, on a bottle label (**2.7**, pp.15-16); or the problem of devising a way to reproduce geological structures in the laboratory. Are these technological or scientific problems?

Teachers in Hampshire have included practical problem-solving tasks in two short electronics courses they have devised for second and third year pupils. In the second year course, which is based on a systems approach, pupils are set quite complex practical problems, such as designing and constructing a circuit for a combination lock (**2.17**). The other components-based module finishes with an exercise in which the children attempt to apply their knowledge and practical experience of transistors used as sensors for light, magnetism, and heat to the production of a device of their own choice (**2.18**).

Other examples of the use of technological problem-solving in science classes are described in Section 5.

Scientific problems with cognitive endpoints

These are problems which require pupils to investigate phenomena and test ideas (including their own ideas) about **how or why something happens**. Examples gleaned from Review working group materials are:

- Why do 'refreshers' make Coke fizz? (**2.9**, p.44)
- What keeps crisps fresh? (**2.9**, p.52)
- What effect does the colour of food have on its flavour? (**2.7**, pp.55-62)
- What happens when a candle burns? (**2.10**, pp.55-62).

The last example in the list is the subject of an interesting account by a Northants teacher of how a problem-solving approach evolved during a series of lessons with a class of 11–12 year olds.

> *During the last two months the children had been investigating 'acids, alkalis and their indicators', 'heating things in air' and 'making and testing gases'. Their ability to apply this learning was assessed by an individual practical investigation of the burning of a candle. The majority of the children found it very hard to organise and complete their investigation within the 40 minutes available. None attempted any detailed quantitative investigation.*
> *Upon reflection it seemed to me that the children's difficulties might have been avoided if they had begun by making a plan of work and ordering the various tasks to be completed. They were used to receiving quite detailed directions before they began practical work. The practical assessment had exposed their inexperience in planning an investigation. I decided to ask the children to spend the next lesson planning a second attempt at the investigation. This time they would be able to work in teams of 4 or 5 and had to organise the tasks accordingly. I reminded them that they would have a glass beaker or jar to invert over the candle until the flame was extinguished.* (Tee, in **2.10**, pp.55-62)

In the next lesson the youngsters made some progress with planning their investigation using networks or charts to show how the tasks they had elected to carry out could be divided up among the members of the team and placed in a sensible order. Then, since some pupils had listed a number of measurements that they thought should be made during their investigations, the following lesson was given over to devising experiments involving measurement. These included an investigation of the effect of the size of the beaker or jar on the burning time of a candle, and a 'totally unexpected' attempt to devise a way of measuring the rate of production of heat by a candle. Apparently, in these conditions, the children's creativity and capacity for original thought was beginning to sprout!

Some teachers in Essex who set out to encourage children's creativity in first year secondary science lessons have entitled their work *Primary Approaches to Secondary Science* (**2.19**) By encouraging children to take an interest in some aspect(s) of a topic or theme (e.g., 'Time', 'Soil', 'Metals'), and allowing them to plan, carry out and report their own investigations, they seek to build on good practice

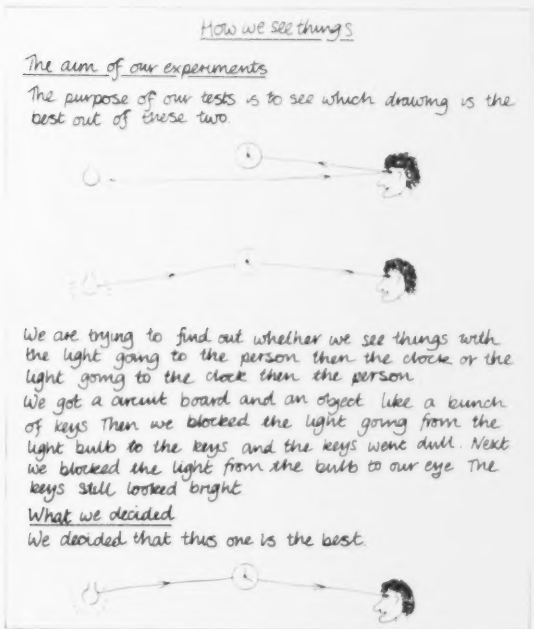
in primary science. (See **Better Science: Building primary-secondary links**.)

The Leicestershire Science Process group (**2.5**) have described an example of a process approach to an introductory unit on light for a mixed ability second year class. The children were given the task of clarifying and stating their views about 'How we see the clock on the wall'. One member of the class, Mandy, wrote about her ideas:

> *I think the light shines from either the sun or the electric light to your eye. Then the light goes onto your eye and shines back onto the clock.* (**2.5**, p.78)

Five different theories emerged from class discussion and, to simplify matters, the students were asked to decide which were the simplest. Then they set about devising and carrying out tests to see if one of these ideas could be excluded. Part of Mandy's account of her investigation is reproduced in Box 3. The teachers who conducted this particular classroom experiment reported how:

> *most students felt it was a taxing but enjoyable activity; they especially appreciated the opportunity to test their own ideas.* (**2.5**, p.84)


How we see things

The aim of our experiments

The purpose of our tests is to see which drawing is the best out of these two.

We are trying to find out whether we see things with the light going to the person then the clock or the light going to the clock then the person

We got a circuit board and an object like a bunch of keys Then we blocked the light going from the light bulb to the keys and the keys were dull. Next we blocked the light from the bulb to our eye The keys still looked bright

What we decided

We decided that this one is the best.

Box 3 *Pupil's account of an investigation* (Mandy, **3.5** p.79)

The Leicestershire group also describe their attempts to apply a process approach to the difficult task of teaching the particle theory of matter (cf. **1.18**). The problem for pupils was to 'come up with some sort of coherent explanation of the way substances behave' (**2.5**, p.103).The basic strategy was to ask children to think of ideas which would provide a satisfactory explanation of one phenomenon (e.g. melting),and then to try to apply these ideas to other related phenomena (e.g. boiling and dissolving).

The approach was tried with two different classes, one a class of 11–12 year olds, the other a group of 14–15 year olds studying an O level physics course. The former had not previously been taught about particle theory in their science lessons, whereas the latter had in previous years. The work with the younger children demonstrated that, given the challenge and opportunity, youngsters are 'capable of forming abstract ideas and testing them against experience' (**2.5**, p.105). With the O level class an interesting point was that, whilst all the pupils came up with the accepted particle model, they found the process of explaining various effects in terms of these ideas difficult. Initially they were worried by the teacher's refusal to let them have the right answer during group discussions, and greatly confused by the prospect of having to organise themselves to carry out a series of (directed) experiments. Expectations based on earlier experiences of school science were being shattered! The teacher involved recorded how, as the lessons progressed, students seemed to become

> *more confident about their own ideas,but ...were much happier when the results and explanations were summarized by me* (**2.5**, p.113).

Clearly there are implications here for what needs to happen in the early years of secondary schooling as well as for the expectations that ought to be generated by external examinations (especially GCSE). Overall the teacher felt that the youngsters enjoyed and benefitted from the process of having to 'think things out for themselves' aided by discussion in small groups (**2.5**, p.114).

When should problem-solving be used in science lessons?

Several SSCR groups,which have developed and tested problem-solving activities, share the view expressed by the Avon problem-solving group (**2.7**, p.1) that it is:

> *more appropriate to look for opportunities within existing commonly agreed topics to introduce activities rather than introduce a whole topic on problem solving.*

Problem-solving should become an integral part of a science course rather than a course in itself. At the same time it must be said that children need to learn, through experience, how to solve problems, and so there needs to be some progression in the complexity and difficulty of the problems pupils are being asked to tackle (cf. earlier comments about the Leicestershire 4th form

physics class). Thus some of the problems devised by the Avon teachers are only suitable if youngsters have had other experience of solving simpler problems. Problem-solving requires skills that can and should be developed (**2.13**).

There are various ways in which problem-solving activities can be incorporated into courses. A topic might be introduced through a simple problem. For example, work on electric circuits could start:

> *Job 1 Use one battery to light one bulb*
> *Job 2 Use one battery to light two bulbs*
> *Job 3 Find a different way to do job 2*
>
> *Within half an hour there is enough material to support a discussion on the topological nature of the circuits, the difference between series and parallel connections and the need for a neat and quick way of recording their activities, i.e., circuit symbols and diagrams.* (Potts, in **2.9**, pp.5-6)

Alternatively, problem-solving can provide a way of encouraging pupils to apply knowledge and skills that they have acquired through other learning experiences. Potts (in **2.9**) describes how a third year module on heat flow and home insulation was restructured in his school so that some 'fairly traditional work on mechanisms of heat flow' was followed by the children being asked to design and perform an experiment in order to find an answer to such questions as:

> *Does the colour of a painted radiator affect its ability to radiate heat?*, or *How does the thickness of loft insulation affect heat loss?*
>
> *They are encouraged to generate their own questions but not discouraged from using one of the samples. ...This approach certainly seems to lead to much more thoughtful and often ingenious design of experiments (than when problem-solving is used at the start of this topic). I also feel more confident that their understanding of the mechanisms of heat flow is being reinforced.*

The following examples drawn from Review materials give a flavour of the variety of ways problem-solving can be integrated into the teaching of science:

1 *Devise an experiment to find the approximate energy content of a peanut* (**2.15**, p.50)
This exercise could follow:
- a demonstration by the teacher that the same amount of energy will cause two different liquids to 'heat up' at different rates;
- the use of a spirit burner to raise the temperature of a known amount of water.

2 *Cheap time* (**2.7**, p.30)
- This is a problem about making and testing simple electrical cells to run an LCD clock, and can be used during or after work on electricity with 11–13 year olds.

3 *Cabbage or Abbage? (Keeping the C in cabbage)* (**2.7**, pp.39-40)
- This involves finding out about various ways of cooking cabbage and designing experiments to see what effects these have on the vitamin C content of cooked cabbage. It is suitable for 11–14 year olds, and can be integrated into work on indicators, food tests or 'Food and Health'.

4 *How much air is there in soil?* (**2.10**, p.23)
- This exercise has been given to students aged from 11–15 years and proved to be useful when carried out after work on earthworms and their effects on soil.
- The students can be asked to measure the amount of air in a soil sample using apparatus on display. 'The novelty lies entirely in the way the pupils are introduced to the investigation'.

5 *Investigating animal behaviour* (**2.5**, pp.88-99)
- This is a group of three lessons which have been used successfully with 15 year old students and may be adaptable for use with 12–13 year olds.
- 'They begin with a straightforward, guided experiment and then become more demanding, with open investigations which the students plan and carry out for themselves'.
- Alternatively, youngsters who can cope more confidently with open investigations could tackle these from the start. The task could be 'Find out how these animals respond to light' or 'What stimuli do these animals respond to?' Or the students could determine the idea for an experiment. Whichever way turns out to be best, 'what matters most is the process of finding out for oneself'.

How does problem-solving relate to practical work?

> *The balance in practical work should be more towards solving problems and less towards illustrating previously taught theory.* (**2.1**, para.60).

It should be obvious from the discussion thus far that problem-solving often, but not always, involves practical activity by the student, *whether the ends are practical or cognitive.* It would be timely, at this point' to reflect on the nature and aims of practical work as currently practised in secondary science education. In their eminently readable and thought provoking study of the subject, Woolnough and Allsop (**2.1**) enumerate the current reasons that teachers and curriculum developers give for doing small-group practical work in science

lessons under four headings, and they consider the extent to which each is fulfilled in practice.

Practical work helps to motivate and interest pupils

Certainly there can be no doubt about the enthusiastic excitement which children find in practical activity when they first encounter secondary school science. But so often that excitement fades:

> *as exploitation of personal interests are replaced by experiments that interest the teacher. Given a choice in science between a double lesson of practical and a double lesson of theory, most would prefer the former – but that may ... simply say more about the need for appropriate alternative ... strategies for teaching theory than about practical work. We also can see the student, so often it is the girls, for whom practical work appears to hold no interest at all – the main concern is with the neat and correct writing up of the experiment.* (**2.1**, p.8)

Practical work helps to develop practical skills and techniques

Is this so? The findings published by the APU suggest that many pupils, by the ages of 13 or 15, have not developed much skill in 'using apparatus and measuring instruments', 'making and interpreting observations' and 'planning and performing investigations' (**1.11**, **2.20**)

Practical work helps pupils to work in a scientific manner

However, although practical work in school science is practical, is it necessarily science? Many of the practical activities in which youngsters engage during science lessons are not. Much that is dubbed 'experimental' bears little resemblance to the activity of practising scientists:

> *it is much more a series of restrictive exercises involving students in activities in a science laboratory, with school science apparatus, on a range of scientific topics.* (**2.1**, p.3)

Practical work helps pupils to learn and understand theory

There are two important comments to make here. First, if this idea refers to the Nuffield-style of 'discovery learning' whereby children are expected to 'discover' currently accepted scientific ideas through observation and experimentation then it is neither consistent with classroom realities nor soundly based. We may not all have been asked the question which one teacher recalls being posed by a perceptive member of a CSE class, 'What did we learn in that lesson that you couldn't have told us in ten minutes on the blackboard?' (**2.21**). But questions like 'What's supposed to happen, miss?! or 'Have I got the right answer, sir?' are ones which we have all heard and which show how youngsters are quick to recognise the rules of the game. An experiment, by teacher or pupil, is perceived to have 'worked' only if it gives the 'right answer'. And even if it does, there is no guarantee that pupils will infer the 'correct explanation' (**2.22**; **2.23**, p.3). Indeed to assume that they should be able to infer scientific principles from observations would seem to indicate a view of how scientists work that is naively inductivist (**2.24**). As Driver (**2.23**, p.42) and others have pointed out:

> *Though pupils are creative in their thinking, it is naive to suggest that they can be expected to re-invent the important ideas of science.*

Secondly, if the assertion being made is that practical work helps students to understand theory better, here again there is reason to be doubtful. A considerable quantity of evidence has been accumulated in recent years which suggests that typical practical work in science lessons may not be as effective in this respect as has been assumed. Thus the APU surveys have indicated that, in spite of the orientation of science courses and practical work towards the teaching of concepts and theories, only a minority of 15 year old pupils draw on and apply some of the most basic scientific concepts (**1.11**, p.190).

None of this is to argue against having practical work in school science. Rather it suggests, as Woolnough and Allsop have done, that we need to rethink the nature and role of practical activities in science lessons. Woolnough and Allsop argue that practical work should be of three types and fulfil three major aims (**2.1**, pp. 41 *et seq.*). Briefly, these are:

- *practical exercises* to develop practical skills and techniques;
- *investigations* to develop in students the habit of working as a problem-solving scientist; and
- *practical experience* to give students a feel for phenomena.

In other words, practical work should contribute to the achievement of one of the major aims of education in science, i.e., the development of **scientific capability**. Youngsters should be learning, largely by first-hand experience, how to observe, measure, estimate and manipulate, how to plan, perform and interpret the results from experiments. These skills and the 'reservoir of tacit knowledge' (**2.1**, p.46), accumulated through practical experiences of phenomena, should function as a resource for the problem-solving process.

As far as developing **understanding** of scientific concepts and theories (the other major aim of education in science) is concerned, Woolnough

and Allsop maintain that practical work is largely inappropriate. Instead they argue that, in the first instance, a student's understanding is extended and refined through discussion, writing and application of ideas to theoretical problems. However, by giving a feel for phenomena, practical experiences can help to make theoretical concepts *meaningful* (**2.1**, p.46). Furthermore, using ideas, which have been discussed and applied to 'paper' problems first, in practical investigations can help to *personalise* the student's understanding.

For further, more detailed discussion of the practical – theory interaction you should consult *Practical Work in Science* (**2.1**, pp.73–7). For our purposes the main point to make is this:

> **Problem-solving or investigational work should be an important part of practical work in science lessons, and this *primarily* for reasons to do with the promotion of scientific capability.**

Why should problem-solving be used in science lessons?

> *An introduction to scientific method contributes to the preparation of ... young people for adult and working life as well as to their intellectual development. It offers practical opportunities ...for the solving of problems in an everyday context.* (**1.1**, para. 8)

Reasons for using the problem-solving approach in school science should have become apparent at various points throughout this section. Here we gather together a number of threads that have run through the past few pages.

In his cogent survey of arguments for problem-solving in school science, Nott (**2.11**) has identified four interrelated categories.

1 The arguments that problem-solving is a particularly effective way of learning because:
- it is an active process;
- it takes account of children's interests;
- the problems can be related to children's knowledge and experiences;
- the process is enjoyable and challenging (and, therefore, motivating).

2 The argument that, since problem-solving is an important part of the activity of scientists, children need to engage in it if they are to understand science and learn to think scientifically.

3 The vocational arguments that the skills and attitudes acquired through solving problems in school are relevant (and transferable to the world of work) and, therefore, to the economic well-being of society as a whole.

4 The ideological arguments that, if future citizens are to be willing and able to participate in, and develop, a caring, co-operative society, then science education should adopt an approach to learning that is essentially cooperative and develops confidence and capability.

Why Use Problem Solving?

1 It is an alternative method of teaching science which also teaches a valuable skill.
2 It is using a skill that can be applied in everyday life to a wide variety of situations.
3 It is an effective reinforcing tool that requires pupils to use and, therefore, understand acquired knowledge.
4 It builds confidence and aids motivation.
5 It can develop social skills by pupils organizing themselves in co-operative groups.

Box 4 Reasons for using problem solving (**2.9**, p.2)

Like Nott, we will not attempt to provide a critique of each category. (Readers are recommended to consult Nott's paper (**2.11**) for a fuller elaboration of the arguments and the assumptions on which each rests). Nevertheless, it should be clear that some of the categories relate more closely than others to the underlying theme of this curriculum guide, i.e., the need for school science to be relevant to youngsters' lives and personally applicable by them in a variety of ways. Pre-eminent among the reasons for problem-solving in the science curriculum are:

- those related to its **educational value for the individual**; and
- those related to the **enjoyment** and **personal satisfaction** that it engenders in students.

Interestingly, the reasons for using problem-solving stated by members of the SSCR working groups focus, for the most part, on the

What are the advantages of such a problem-solving approach to the applications of science? Here are a few suggestions:

(i) A problem-solving approach to a familiar application of a particular science topic can help pupils to constructively relate this topic to the everyday world, and hence to understand it better.
(ii) Practical problem-solving has the sensory advantage of practical work in general with, perhaps, a greater scope for curiosity and creativity.
(iii) This approach gives the science teacher greater opportunity to discuss the social, environmental and other implications of science (in line with, for example, the national GCSE criteria).
(iv) It discourages the pupils from excessively compartmentalising their knowledge (a common problem at present, and one reason for including problem-solving, and even technological problem-solving, within science even if a separate problem-solving technology course exists).

Box 5 Advantages of problem solving (**2.2**, p.6)

educational value of the such experiences. Those reproduced in Box 4 and Box 5 seem to be fairly typical.

Thus the authors of a Cambridgshire booklet on problem–solving in school science enumerate several of its educational benefits. For example, problem–solving fosters various sorts of skills, 'provides a natural cross–curricular approach' and 'gives free rein to creativity'. In addition it is 'highly motivational' for pupils (**2.26**, p.11).

In practice, as Heaney has pointed out (**2.14**):

> *Most teachers like to use a problem-solving approach from time to time because they find that students enjoy it and it stimulates their interests.*

We have already quoted some supporting instances of this from a number of working group publications. Here are a few more examples.

The authors of a set of problems for less able pupils have this to say about their experience (**2.25**, p.1):

> *Not all our ideas worked for all the pupils in our groups, but those ideas which were successful helped pupils to:*
> *work together*
> *communicate*
> *think logically*
> *experience success and*
> *enjoy themselves.*
> *Even groups which did not complete the task ... usually gained something from the attempt.*

Members of the West Yorkshire Science Applications group commented about their experience of trying various problems (**2.2**, p.48):

> *One observation, so far, is the dramatic effect these exercises have had on staff in terms of mode of approach to their general teaching: most people realise a significant increase in pupil motivation.*
>
> *Most pupils got a great deal from these two lessons ...*
>
> *Pupils enjoyed the task; it was a novel situation.*

The last observation prompts us to introduce two words of caution.

- We would be wary of assuming that problem-solving will automatically continue to be an enjoyable experience once the novelty factor has worn off. (Perhaps this is an argument for using problem-solving as just one of a variety of teaching methods, rather than having an entire module on the practice of solving problems).
- We should be careful not to take it for granted that an enjoyable experience is necessarily a valuable *learning* experience.

The following extract from the 'personal view' recorded by a member of the Wiltshire problem-solving group (Potts, in **2.9**, p.7) seems apposite:

> *About four years ago we introduced a problem-solving module into the 3rd year Physics course ... There was plenty of enthusiasm from the customers but not much evidence of scientific activity. The intuitive approach predominated ... certain types of so-called problem-solving may have a negative effect on the understanding of the nature of scientific activity by emphasising the intuitive component at the expense of proper measurement and evaluation ...*

Potts goes on to indicate the benefits of using problem-solving in a context such as the study of heat flow and home insulation.

A similar experience is described by the convenor of the same group (Nicholls, in **2.9**, p.14) who recounts how she developed problem-solving as one of her approaches to teaching science, having found that 'egg-race' problems were enjoyed by many of her pupils:

> *The Egg-Race activities evolved into the investigation type of problem as this seemed to have greater scientific content and slotted conveniently into the existing syllabus. ... With experience we have survived this activity, made better scientists out of our pupils and remain sane.*

One of the points Nicholls makes (**2.9**, p.15) in her Eight Point Survival Plan gives us an indication of how enthusiastic and committed children can be when they have become engrossed in an investigation which has captured their interest and imagination:

> *I'm prepared for heated disagreements in the groups. It's their problem and they're personally involved.*

The comments we have quoted here illustrate something of the variety of benefits that can flow from problem-solving in science lessons. They are further borne out by the findings of a research project conducted in schools in the Oxford area (**2.1**, pp.52-53). Responses from teachers and pupils to the introduction of investigational practical work indicated that:

- students experience a sense of satisfaction and achievement from solving 'their' problem;
- their commitment to solving the problem tends to be very strong;
- the quality of students' work on their own open-ended problems tends to be greater than when doing the 'teacher's practical'.

Doubtless the introduction of investigational activities into science lessons has great practical implications for such matters as classroom organisation, the content and planning of science courses and the role of the teacher. One of the reasons why the factual and conceptual content of

science courses needs to be reduced is so that more 'space' can be provided for problem-solving and other learning activites (see **Better Science: Choosing content**). As far as the teacher is concerned, s/he changes from being an apparently omniscient source of knowledge to being a scene-setter and a director and facilitator of activities.

> *This approach requires much self-discipline on our part – we are so used to setting up experiments to get the 'right result'.* (Kramer, quoted in **2.5**, p.89)

The potential benefits to young people studying science should outweight any reservations we may have about beginning to bring about change. The following extract from a conference paper (**2.27**, p.7) nicely encapsulates the benefits and the difficulties associated with problem-solving approaches:

> *I know of no-one who has seriously emphasised problem-solving approaches within their teaching who has then retreated from it saying it is not worthwhile. ...*
>
> *I am not quite sure why problem-solving can be so involving and energy-releasing. It has something to do with 'reality-connections'; (this is not merely a paper hoop held up by the academic for me to jump through); it has something to do with being given responsibility for getting on with things, with becoming teacher-independent; it has something to do with breaking out of receipt-following routines; it has something to do with seeing,or being persuaded to see, the worthwhileness of a task to which one gives time.*
>
> *A word of warning. Problem-solving does not automatically continue to be stimulating and enjoyable. Such experience depends largely on a sufficiently regular experience of success. ... The 'glow' comes from the disappearance of the feelings of inadequacy. The task for the teacher remains difficult: it is not simply to devise ingenious and imaginative problems. It is to devise problems that are challenging, but not impossible, for particular problem-solvers.*

The last word on the benefits of having more problem-solving and investigational activities on offer must come from the 'customers':

> *I thought the work we have been doing is better than all of last year. I like this term's work because we all work more of a group and we were allowed to discuss and help each other. I don't like writing the gaps in booklets and not being able to work in groups.*
>
> *I liked setting up and doing the experiments and finding out for ourselves ...*
>
> *We think that this unit has been really good because we could think up our own experiments instead of ... us copying from the book,this made the experiments more exciting and more interesting. Science is exciting.*
>
> (Comments from Wiltshire children, reproduced in **2.9**, p.21)

SECTION THREE

Ways and means: vary the contexts

Above all, the justification for including societal material in the science curriculum is that it helps make science more interesting and enjoyable. We should be showing our pupils the relevance of science to the everyday things with which they are familiar. In this way science becomes less mysterious and more a real-life, human activity. As science teachers we have an interest in making science enjoyable and we have a duty to help pupils understand the crucial role of science and technology in the world about them. (A teacher, quoted in **3.1**)

Contextualising school science

School science always has a context of some sort, whether this is the classroom or laboratory, an examination syllabus or a textbook. Too often, it would seem, the scientific ideas and processes covered in science lessons are almost exclusively related to theoretical contexts. The school science experiences are insufficiently connected (and, therefore, perceived to be unconnected) with situations encountered *outside* school or even to youngsters' experience in other areas of the curriculum. The diagnosis is expressed pointedly in *Science 5–16* (**1.1**, para. 45):

Although there are some impressive exceptions, too much of the time spent learning science by too many pupils consists of the accumulation of facts and principles which have little perceived, or indeed actual, relevance to their daily lives as young people or as adults. ... Most experiments and many illustrative examples are laboratory-based and divorced from the present-day world.

Certainly there are, to an ever increasing extent, impressive exceptions to this general observation of current classroom practice (see, e.g., **3.1**). This probably reflects both the changing mood of science teachers – a mood that has been very evident among those teachers who have participated in the SSCR – and the external pressures for change, coming, perhaps most obviously at this time, from the GCSE National Criteria, as these are made manifest in new syllabuses and examinations.

In any case a growing proportion of the science teaching profession is becoming concerned to enrich youngsters' experience of school science by making more use of the interconnections of science with human issues and everyday realities in their teaching. In effect they are endeavouring to **contextualise** school science.

By 'contextualising school science' we mean the interweaving and integrating of theoretical principles, laboratory work and so on, with human contexts and issues.

Describing the context as 'human' emphasises both the humanness of scientific activities and the implications of those activities for human beings, both individually and collectively (see *Palatable science for all* later in Section 4). In Box 6 we offer some fairly loose definitions of the various sorts of human contexts and issues to which school science can relate, in the hope that this will clarify what can be a confusing plethora of terms.

School Science in Context

Type of context	*Studying science in relation to...*
The individual person	oneself; one's personal ideas, beliefs, opinions, values, interests and aspirations;understanding oneself; one's personal well-being (health);
Social and cultural	domestic, family and community life; leisure and recreational activities; health issues, medical and social services; citizenship and politics; religious and metaphysical beliefs and values; ethics;
Historical	the historical development of scientific ideas and applications, and their social and cultural interactions;
Environmental	understanding the natural world about us; interactions of science and technology with the environment (local, national and global);
Industrial, commercial and economic	processes and artefacts produced by technological and engineering activity (see Section 5); industrial and agricultural production; the workings of industry; the consumption of goods and services; employment.

Box 6 A taxonomy of contexts for school science

To place school science in context is to weave it together with a problem or set of circumstances to which students can relate. The relatedness (relevance) of a problem or situation *to the student* can arise from the fact that it is a familiar part of their everyday life. Alternatively, youngsters may see a context as relevant because it links with some aspect of their developing ideas, beliefs, values, ideals and interests.

The extent to which particular contexts or issues are regarded as personally relevant by pupils will vary from one individual young person to another.

Factors like age and maturity, gender, cultural background and the locality of the school will have varying degrees of influence. For instance, 15 years olds are, perhaps, more likely than 11 year olds to be taking an interest in the world of work (industry, commerce, health services, etc.) or in wider social and environmental implications of science and technology. Girls are generally more interested in science when it is presented in a human context (see **Better Science: For both girls and boys** and **1.8**, p.85),although, as the authors of one piece of SSCR work remind us, 'any approach which treats science in this way is likely to be more meaningful for boys as well' (**3.2**, p.2). Variations in culture, social background and local environment are such that what is an everyday experience for one pupil may be entirely outside the experience of another. But, of course, children, like adults, can also be more interested in unfamiliar objects, places and customs than in those things that are part of their day-to-day experiences. The point at issue is that science education should be concerned with arousing and extending young people's fascination with and curiosity about their world, whether or not this is their immediate surroundings and, however ordinary or extraordinary it may seem.

Next we look at some ways in which Review groups have sought to broaden the appeal of school science and heighten pupils' awareness of the personal, social, industrial and other implications of science in society.

Some examples from SSCR materials

> *If we had done things in class that related to what happened everyday, that would have made it a lot more interesting.* (An ex-pupil, quoted in **2.4**).

What follows is a selection of descriptions of approaches developed by Review working groups. These can be seen as attempts by teachers to find ways of implementing one or more aspects of the Review's statement of aims for science education in which so much weight was laid on the personal, societal, technological and cultural dimensions of science (**3.3**). The examples are grouped together under a number of the categories of contexts and issues listed in Box 6.

Individual, social and cultural contexts

Several of the problems designed for 11–13 year old students by the Avon problem-solving group (**2.7**) relate to life in or around **the home.** 'Cabbage or Abbage? (Keeping the C in Cabbage)' has already been mentioned. Cooking, cabbage and vitamin C take a science lesson straight into the home and form a link with Home Economics lessons. The practical activity could lead to discussion of the merits of different cooking methods,health issues, and so on. The authors make this suggestion (**2.7**, pp.39-40):

> *Experimental results and a survey of cooking habits amongst pupils' parents and friends could form the basis of a* Which? *report; the findings could be presented in a variety of forms; for example, a written report, dramatic presentation by practical groups using posters, a chat-show interview, or even a short video presentation to other groups.*

Another problem (**2.7**, p.27) asks pupils to picture themselves in domestic circumstances that will be familiar at least to some:

> *You want to run a bath while watching the last five minutes of your favourite television programme. Something is needed to warn you when the bath is full.*
>
> *Things to think about:*
> - *It must be easy to use.*
> - *You should be able to set it to a certain water level.*
> - *It must be safe.*

The Avon package also includes a problem on the identification of coloured food additives (in lollipops) using chromatography, which relates to concern about **food and health**. A similar activity,appropriate for those with a sweet tooth, has been devised by a Wiltshire problem-solving group (**2.9**)–this time the subject of the study is Smarties! There is scope here for developing a broader awareness of the issue of food additives. For example, the Wiltshire problem is set in the context of food regulations in the United States and how they differ from those in the UK; the effect of the US regulations is that all colours of Smarties but one are banned on the American side of the Atlantic!

Personal and social aspects of health provide the context for a third year study of microbes which a working group based in Belfast have produced (**3.4**). The emphasis in the lessons is on:

> *providing the necessary knowledge and the opportunity to make informed choices where personal hygiene, food hygiene and vaccination can affect individuals' health and prevent the spread of disease.*

The material includes a computer simulation of aspects of the storage and cooking of food.

A number of SSCR groups have developed ways of dealing in science lessons with controversial **ethical issues** related to health and medicine (**2.16**, **3.2**, **3.5**, **3.6**). For example, some Staffordshire teachers have devised an approach

to the implications of employing 'genetic probe' tests during pregnancy, which involves pupils in a directed reading activity (**2.16**, pp.620-625).

Teachers in North Tyneside (**3.7**) have conidered how to:

> *introduce pupils to some aspects of electricity in the home, hopefully in a stimulating and relevant way.*

The group reiterate the concern which many have expressed over the APU and other research evidence that only a minority of 15 year olds 'have a reasonable working understanding of the idea of electricity', a fact that can hardly be conducive to living at ease with electrical systems and appliances in the home, maximising its usefulness — and minimising its cost. The group sees three particularly important causes of this poverty of understanding of electricity,electrical circuitry, and so on:

(a) *The tendency of much of the existing material to drift towards unnecessarily complex theoretical models to explain electrical phenomena, and an over-reaction on the part of some of the rest in... reducing it to a mechanical activity, devoid of understanding.*
(b) *Lack of interest ... generated in part by (a), but also stemming from a failure to recognise the relevance and importance of the topic.*
(c) *The inability of pupils to transfer learning from the circuit board models in the laboratory to real life situations in the home.*

The group's attempt to challenge these problems involves a series of learning activities which are 'as personal and realistic as possible'. These include:

- a practical introduction to insulation, short-circuits,mains electricity and separate switching for two appliances, with the help of realistic models;
- calculations of costs of mains electricity based on a 'A typical day in the life of the Watt family'.

The pupil materials (**3.7**) were designed for use with lower-ability 14–16 year olds, but could be more widely applicable.

Variations in youngsters' **cultural backgrounds** are put to good effect in some of the ideas recorded by a Leicestershire working group (**3.8**) (See **Better Science: Working for a multicultural society.**) For example, there is an account of how a number of studies of germination and growth were carried out by a class of 11 year olds using fenugreek, a vegetable that was familiar to some and unfamiliar to others, rather than mustard or cress, nicely illustrates how:

> *teachers can make basic science teaching more interesting, stimulating and challenging by drawing on a variety of cultures for source materials.*

More interesting, that is, for teachers as well as pupils. The fact that one teacher who tried this approach had never seen fenugreek before made the investigation more realistic for all concerned (**3.8**, p.10).

Industrial, commercial and economic contexts

A group of Cleveland chemistry teachers have put together a learning package (**3.9**), which aims to help students to appreciate the

> *connection between the science studied in the classroom and that applied in industry.*

Work in school on various techniques for separating substances is supplemented by studies of one or more local chemical companies, including **visits** to the industrial plant. Issues such as **pollution control** and the **social responsibility** of industry can be raised on site.

A video-recording of operations on an industrial site is an alternative to a visit as a way of connecting school science with industry. One such video – of a local engineering firm – has been produced by an SSCR group in Northern Ireland. The video can be used to relate laboratory investigations of the mechanical properties of materials to their use in engineering processes (**3.10**). A group in the North-East (**3.11**) have developed another, rather different, approach to industry in their locality. They have devised an exercise round an imaginary, but recognisably real-life industrial scenario (see Box 7), which require the pupils to engage in role-play and make a series of decisions.

TYNIUM - A WONDERFUL METAL?

BACKGROUND INFORMATION

A new metal called TYNIUM has been discovered. It is quite rare but it is believed to be very useful. It is dug up as its ORE called TYNETITE. Tynetite is found in Norway but only England is allowed to extract Tynium from it. This ore is very light and there are only small quantities of it. It is found as part of rock which has some impurities. It must be transported quickly from the mines to the processing factories. From here the metal should be transported quickly to London for turning into objects.

WHAT YOU HAVE TO DO

You will be organised into groups of 3-4. Each group will be a MINING COMPANY. Choose a NAME CARD to rest on your bench. Use this for all letters, posters etc. Your company is trying to win a £50 million contract for the Newcastle area. You have to draw up detailed plans to satisfy the Government (your teacher!). It is your ideas we are looking for.

Each person should have a JOB BADGE. (5 people max.)

HOW WILL YOU DO THIS?

There are FOUR STAGES that have to be completed:-

I - Purify the Tynetite ore,

II - Extract the metal Tynium from Tynetite,

III - Use a map to position your factories,

IV - Decide the best uses for Tynium.

WHAt INFORMATION AND EQUIPMENT DO YOU HAVE?

INFORMATION TABLES about the metal and its ore,

Felt pens, paper,

MAP of the area and a CLEAR OVERLAY for initial decisions.

Company DECISION-MAKING Sheets.

Box 7 A real-life industrial exercise (**3.11**)

'Designing a new yoghurt' is another example of an activity where decisions have to be made in an imaginary commercial setting. This role-play exercise has been devised by members of the SSCR Sheffield Biotechnology group (**3.6**) for use with 14–16 year old students, after they have made their own natural yoghurts (see Section 6). In the first stage of the exercise students are assigned one of three roles: customer researcher, scientist or market adviser – and consider, in pairs, various sorts of evidence (Box 8). The three roles are then combined in a meeting of a New Company Board whose task is to make decisions about a new yoghurt which the company wishes to develop. In the authors' words, the activity is intended to help pupils

> *gain insight into some of the forces at play in determining decisions in the food industry* (**3.6**, Biotech 1, Teacher's Notes, p.iv).

Designing a New Yoghurt

Work as a pair. Your teacher will tell your group whether you are either:
(a) customer researchers,or
(b) yoghurt scientists, or
(c) marketing advisers.
When you have been told which group you belong to then read and carry out the instructions below, for your group only. ...

A. Instructions for Customer Researchers
Between 1970 and 1980 sales of yoghurt in the U.K. increased four fold. But the selling of yoghurt is a competitive industry. .... The yoghurt companies need ways to increase sales. To do this they need to know what the customer thinks of their product.

B. Instructions for the Yoghurt Scientists
... Recent scientific findings have suggested that our health is connected with what we eat. Your job as scientists is to interpret these findings for the yoghurt company board. At the moment the public is worried about chemicals added to food and their effect on health. ...

C. Instructions for the Marketing Advisers
The reasons why people buy things change from time to time. These fashions happen with food,including yoghurt, just as they happen with clothes and records. ... Companies who want to go on making a profit must know about these changes. ...

***Box 8** Making decisions in an industrial/commercial context.* (**3.6**, *Biotech 1*, pp.11-12)

Agricultural practices can also provide interesting contexts for school science. Several SSCR working groups have focused their attention on the contribution that **rural science** can make to the science curriculum (see also **3.12**). For example, the Rural Science working party in Hereford and Worcester (**3.13**)recommends that the science and technology of the production of food, using plant and animal resources,should be an integral part of the science curriculum for all children during their first two years at secondary school. The group's preference is to use sugar beet and poultry as examples of food production, partly for practical reasons, but also because, in their view,

> *children aged 11–13 are interested in growing plants and keeping animals and will be stimulated to learn more about the scientific reasons for particular aspects of husbandry being adopted by farmers.*

Environmental contexts

Several SSCR groups have developed ways of introducing **earth science** perspectives into science teaching. Work on aspects of local geology,for example, can help pupils to become aware of:

> *the source, extraction and economic value of everyday materials which they will continually use throughout their lives* (**3.14**)

and can generally enrich young people's appreciation of their natural enviroment (**3.15**, p.5). Moreover earth science studies can provide interesting contexts for learning science concepts and skills (see **1.1**, Para.39). Some of the classroom material prepared by Review groups shows,for example, how learning about crystals and crystallization can be made more interesting for youngsters by being interwoven with studies of rocks and minerals (**3.16** and **3.15**).

An earth sciences approach to studying the natural environment can also lead into consideration of such issues **as conservation of material resources** and **environmental pollution** (**3.17**). The implications of opening a new sandstone quarry in the vicinity of a small scenic village are the subject of a role-play exercise which teachers from Newcastle-upon-Tyne have produced (**3.18**). The activity provides an opportunity for 13–14 year olds to relate familiar uses of materials from rocks to difficult planning decisions associated with the extraction of these materials.

Environmental and archaeological issues connected with a real quarry are the subject of a case study devised by a group based in Belfast (**3.16**). In this case the pupils are asked to adopt the roles of various participants in a Court of Enquiry which was actually held in Armagh during 1985. The question before the court was whether or not the owner of an existing limestone quarry should be permitted to extend his operation,given its close proximity to the remains of an Iron Age settlement which is an important part of the cultural heritage of Ulster. Although the activity was designed for 12–13 year olds it could be used with older students.

Of course, not every piece of SSCR work on environmental contexts for science is concerned with earth science. For example, one of the units of a package developed by the Essex Primary Approaches to Secondary Science group (**2.19**) concerns investigations of *litter* by first year secondary children. The sort of work which one group of pupils became involved in is described by the authors of the unit (**2.19**, p.7):

> *Some children, under supervision, gathered pieces of waste material from demolition sites. They were asked what they wanted to find out about them. Here are some of the questions: Does it bounce? Can it bend? Can it stretch? Will it break? Can you cut it? How heavy is it? How big is it? Can you catch it? Does it go rusty? What does it look like under a lens? Each would choose a material to examine and investigate and write about?*
>
> *Here the topic of litter developed into an investigation into materials.*

Others in the class became interested in the feasibility of **recycling materials**, or in the decomposition of different types of material.

Historical contexts

Only a few Review groups started out with the specific intention of developing historical approaches in school science. Thus, a group in South Wales (**3.19**) has created a number of teaching units which are largely, but not exclusively,concerned with the history of local chemical industries. The units are intended to impart an historical dimension to science lessons for the 13–16 age group,thereby increasing pupils' awareness of the physical remains and social impact of past industrial activity. For instance, the process of iron extraction can be taught not just as a technological process, but also 'as an activity of seminal importance in the development of the local community' (**3.20**). Clearly there is scope in this sort of work for projects involving teachers from history or social studies departments as well as science teachers.

Other groups have sought to make use of historical aspects of science and technology in a variety of ways. The Sheffield *Biotech* material (**3.6**) includes an exercise where pupils consider the historical development of the manufacture of human insulin from genetically engineered bacteria as an illustration of ways in which science,technology and society interact (see Section 6).

A course which has been developed in Somerset for first and second year secondary pupils (**3.21**) makes use of **astronomy** in science education. As well as engaging in practical investigations – especially investigations of their own ideas – children are encouraged to think about past ideas about such phenomena as sunrise. Such work can help youngsters to see that scientific ideas change through time and to see that 'past scientific explanations were valid in their own time' (**3.3** and **3.22**).

Using episodes from the history of science in lessons can be a valuable way of conveying to children the humanness of science and scientists (see Section 4 and **3.22**) and, for example, the notion that interpreting evidence is often problematic. One of the earth science productions mentioned earlier (**3.16**) includes an activity in which pupils examine a scientific controversy, early in the history of modern geology, between representatives of two opposing schools of thought: the 'neptunists' and the 'vulcanists'. In part the debate revolved around the question of how a particular type of local (Irish) rock had formed. The main point is that both parties were able to interpret the same observations in quite different ways.

Contexts, problems and active involvement in learning

Consideration of the specific learning activities we have just described will, we hope, not just have provided you with some interesting ideas for lessons. They are also intended to provide a demonstration of how emphasis on process (problem solving) and context can go hand in hand; the two ways of making science studies relevant and applicable are often combined together in a single piece of teaching/learning material.

Where a group's main concern has been with problem-solving, it is emphasised that problems set should be 'relevant to the pupil' (**2.2**, p.6). Thus a group based in Canterbury (**3.23** and **2.13**) have endeavoured to ensure that problem-solving:

> *relates to real-life situations as well as providing valid exercise of an important science process.*

The Avon problem-solving group believe that providing 11–13 year olds with opportunities to solve problems should 'begin to make pupils aware of the interactions between Science, Technology and Society' (**2.7**, p.1). On the other hand, working groups whose concern has been to contextualise some aspect of school science have often included problem-solving in the learning activities they have devised. Sometimes the problems are wider than either of the categories of scientific problems discussed earlier (Section 2: *What sorts of problems*) in that considerations other than purely scientific ones need to be taken into account in order to achieve a satisfactory solution, or reach a balanced and sensible decision.

A second general point is that whether the emphasis is on problem-solving or on contexts

what is important is that the students are *actively* involved in a *variety* of learning activities. The concerns of this section interact here with those of the companion guide, **Better Science: Approaches to teaching and learning.** Here the focus is on varying the contexts for science and encouraging children to apply the knowledge and processes of science to a variety of problems and issues; there it is on describing and exemplifying a wide assortment of approaches to teaching. Perhaps the relationship between the two Curriculum Guides could be summed up thus:

> **Extending and varying the range of contexts and problems in science lessons makes it highly desirable, perhaps even necessary, that science teachers utilise a greater selection of learning activities than is currently the norm.**

An ASE occasional paper (**3.1**) which was published a few years ago shows how a variety of teaching approaches can be used to promote pupils' awareness and understanding of the personal,social and other implications of the development and application of science and technology in society.

Some examples of non-SSCR work

Efforts to make school science more relevant to young people have not, of course, been confined to Review working groups. We shall now consider briefly science curriculum renewal activities in which other individuals and groups have been engaged during the Review's development phase. Some of the most creative work has been done by the ASE's Science and Technology in Society (SATIS) project. The few paragraphs on the SATIS project which follow have been written by the Project Organiser, **John Holman**. Comments by teachers and pupils quoted in the text are taken from the SATIS *General guide for teachers* (**3.24**).

Science and technology in society — the SATIS project

The SATIS project was initiated by the ASE in 1984 to develop resource materials linking secondary science courses, particularly those for 13–16 year olds taking GCSE, to social and technological applications and issues. The materials were published during 1986 as a collection of units, each consisting of teachers' notes and students' worksheets. A complete list of the unit titles is available from ASE, Hatfield.

Taken together the units do *not* comprise a complete course. Instead each one has links to major science topics and is designed to be used within *existing* science courses. Generally speaking a unit will require a minimum of two periods (about 75 minutes) of classroom time, though this will depend on how much of it is attempted. The material is meant to be used flexibly and selectively, and it is expected that teachers will often want to modify it to suit their own purposes. For example, some may wish to adapt particular units to suit less academic students.

The interactive approach

Instead of simply reading or listening, SATIS units are designed to get students actively involved in a variety of learning activities: comprehension questions, discussion, simulations, role-play, decision-making, problem-solving, surveys and so on. Experience has shown that teaching methods like these can be very effective, particularly where students are interacting with one another in small groups. For example, discussion is rare in science classes, yet many children respond positively when asked for their opinions. Students who feel they have little to offer in an ordinary science lesson often become involved and committed. The unit on *Test-tube Babies* (No. 206) links work on human reproduction with the controversial topic of *in vitro* fertilisation and encourages students to become involved in discussion. What are test-tube babies? What are the implications of frozen embryos, surrogate motherhood and embryo implantation?

In fact one of the benefits of the approach advocated by the SATIS project is that it helps widen the appeal of school science. During trials of the units teachers commented on the way that students who normally had little to offer in science lessons found they could contribute positively to SATIS activities because they often involved skills not normally called for in science. The following comments from a teacher who had used *Should we Build a Fallout Shelter*? (No.608) illustrate the point:

> *I was not able to anticipate their reaction to a role-play exercise,as 'physics' has not included such exercises before. It was very easy and successful,largely I believe because of careful choice of expert witnesses. I gave the roles to pairs of students, who were close friends. This seemed to give them confidence, and the class enjoyed the empathy and interaction between them. We benefited from an excellent Mayoress, played by a girl who tends to be apathetic in physics lessons, but revelled in the opportunity to use her talents.*

For many science teachers, such approaches to teaching are relatively novel and so the SATIS *General Guide for Teachers* (**3.24**) offers guidance, along with ideas and tips for other ways of bringing the science curriculum closer to everyday life.

But is it science?

One problem that some students, particularly the more examination-conscious ones,may have is that they tend to see the subject matter as peripheral to their studies. A fairly typical comment of this sort was the remark made by one student who had completed work on *Chemicals from Salt* (No. 307):

> *It tended to get away from the chemistry aspect and some of the questions wandered onto more geographical problems than scientific. ... Personally I'm more worried about my exams.*

With greater emphasis, in GCSE courses, on social, economic, technological and ethical aspects of science, this attitude should become less common. In any case, comments such as these were relatively rare, and *most students welcomed the change of activity and the emphasis on real-life things*. More typical is the comment by a student about *Recycling Aluminium* (No.310), which begins with an exercise to estimate the amount of aluminium used at home each week:

> *At least we were tackling a real problem in the real world, and not some sort of artificial problem in school.*

Because the units extend school science, they are often cross-curricular in character. Some science departments have taken advantage of this and the considerable interest shown by non-science departments, and have met with teachers of geography, personal and social education, and so on, to coordinate the presentation of related subject matter, with the aim of avoiding duplication.

There isn't always a right answer

The open-ended nature of some of the SATIS units can present problems at first for students who are used to the security of the more closed, or single-answer problems which are a normal part of school science. One teacher's experience of using *Fluoridation of Water Supplies* (No.401) makes the point:

> *The main problem seemed to be their difficulty in realising the difference between facts and opinions, and in seeing that it was possible to have differing opinions and that there was not necessarily a 'right' answer.*

Nevertheless, it is important that young people have opportunities to tackle difficult issues in science lessons if their science education is to contribute to preparation for real life, where decisions usually involve compromise, imperfection, and no single right answer.

Other useful sources

The SATIS approach to increasing youngsters' understanding of the interactions between science, technology and society is to insert work on applications and science-related issues at appropriate points in science courses (**3.24**, p.22). A rather similar approach has been developed by the *Physics Plus* project which has provided a series of examples of short studies of applications of physics in the form of small pamphlets (**3.25**). The editor of the material has acknowledged that one important consequence of introducing contemporary applications into science courses in this way is that teaching materials and syllabuses need to be kept under continual review (**3.26**).

An alternative approach, which has been adopted, for example, by the production team of *Salters' Chemistry* (**3.27**), is to start with the applications and issues and seek to develop scientific concepts and principles through study of these (cf. **3.28**). In other words, applications and issues can be used to provide contexts for learning science – contexts to which young people can relate. The Salters' course builds the study of GCSE chemistry around such topics as *Keeping Healthy* and *Transport*.

Finally, a recent book entitled *Science in the Locality* (**3.29**, p.1) addresses, in a very practical manner, the problem of:

> *how to bridge the gap between the science of textbooks and examination syllabuses and the science encountered in everyday life.*

The greater part of the book consists of a collection of detailed case studies of ways in which teachers have used aspects of their local environment as contexts for teaching science. The examples described are such that, in every school, it should be possible to adapt at least one of them to local circumstances. Waterways, bridges, construction sites, markets and grassland are usually not far away. And weather, the subject of one study, is with us all!

SECTION FOUR

Ways and means: create interest and cultivate curiosity

A school science that appears remote from the personal may well hold little appeal for the average child. ... it seems possible that teachers might want to change the image of science that their teaching conveys. **(4.1)**

... the teaching of science should impart knowledge of ... the nature and limitations of scientific method, the history of science and the social roles of science and technology. **(1.7)**

Broadening the appeal of secondary science studies

In Section 1 we argued that, if school science relates to children's own ideas and experiences, it is more likely that they will find learning science interesting, enjoyable and meaningful. Having now looked at some examples of approaches to teaching science that have been developed by SSCR groups and others, it may be worth pausing for a moment to reflect on the contributions such approaches can make to the very important task of broadening the appeal of secondary science education to boys and girls.

Presumably, as science teachers, we want to stimulate and encourage youngsters' curiosity about the natural and technological world. Therefore we are, quite properly, concerned to foster interest in, and enthusiasm for, science itself – as a way of finding out about the world and as a growing body of ideas and factual information. Many young children exhibit this curiosity and interest at primary level and in the early stages of secondary education. However, only relatively few seem to maintain their enthusiastic interest throughout their period of secondary schooling. The decision of 14 year olds to do more science may be related to factors other than their like or dislike for the subject. Often it is connected with career aspirations, a liking for the teachers, or a feeling that they have not done too badly in science so far. The fact that a very high proportion of teenagers carry on, often through choice, with studying science until they are 16 does not necessarily mean that they are suitably enthralled by the process. The personal experience of teachers and educational research evidence (see **0.1**, **1.8**, Section 1) seems to indicate that many youngsters, perhaps especially young adolescents, are less than enamoured with school science.

Palatable science for all?

As science becomes a compulsory part of the curricular diet of all young people right through their compulsory schooling, it behoves all involved in the planning and provision of science courses to do every thing possible to maximise both the nutritional value and the palatability of the menu. Clearly individual tastes vary greatly; one person's educational meat may well be another's poison. So a varied menu should be the order of the day. And, of course, tastes can change with the passage of time and can be cultivated ...

In essence the problem of how to broaden the appeal of school science to young people is the problem of how to alter the currently purveyed images of science. As Jennings **(3.29)** has so succinctly expressed it:

for most children, these processes of science are remote. Science appears impersonal, infallible and all too often destructive.

The humanness of science

Fundamentally the solution must lie in providing children with experiences which enable them to fully appreciate the *humanness* of science — and technology (see Section 5). We need to present science to pupils in ways which will help them to see it as a co-operative human activity. Some of the work described earlier in Section 3 illustrates how, by various means, it is possible to do just that. Clearly members of Review groups have been concerned, to varying degrees, that youngsters should become aware, for example:

- that science is affected by the social and cultural context in which it develops; it is, therefore, characterised by subjectivity as well as objectivity; **(3.6, 3.8)**
- that scientific ideas are provisional and not permanent, and they are often controversial; **(3.16)**
- that, although the science which pervades many present-day societies and cultures, through its ideas and applications, is historically rooted in Western European culture, validity is not the exclusive possession of this contemporary science and its associated technologies; **(3.8, 3.21)**
- that applying science to solve problems can

often create new problems, practical and/or social, ethical and environmental (**3.6, 3.11**).

Creating opportunities for pupils to relate the science they are learning to various human contexts and issues, both local and global,and to see it from historical viewpoints should help to promote a sense of the humanness of science (**3.22, 4.2**). But,as we have sought to demonstrate, this is not all that can be done.

The accessibility of science

Children also need to discover that science is an *accessible* human activity. It is a creative process in which they can participate by investigating phenomena, testing ideas (including their own ideas) and using their knowledge and skills to solve practical problems; such first-hand experience of *doing* science is an essential complement to the second-hand experience of the activities and ideas of professional scientists. In addition it is important that youngsters be encouraged to develop and express personal views and opinions about scientific explanations, about the effects of science on society and about science itself.

Teaching science and teaching about science

The way in which teachers (and others, for example, in the media) present science always conveys to youngsters an image of science, an impression of what science is like. In effect, science teaching involves *teaching about science* (as a cultural phenomenon) *as well as teaching science* (processes and knowledge). Clearly the concern to communicate to students images of science that conform more closely to reality has implications for science teaching and curriculum renewal in schools. In the first place those who teach science may need to make explicit their beliefs about science and examine (possibly re-examine) these in the light of reading and discussion with other colleagues. In other words,one of the first steps teachers wishing to alter their classroom practice should take is to reflect on the nature of science, to consider, preferably in groups, its scope and limitations, aspects of its history and its social, economic and political interactions. The recorded experience of the SSCR Science Process group in Leicestershire bears this out (Box 9).

> As teachers of science, we need to have a view of how scientists go about their work. In order that we may encourage a spirit of scientific enquiry in our students, we need a clear understanding of what we mean by science as a process.
> The process of science has been the subject of debate for many years and the arguments have been long and sometimes heated. Yet, we often assume that scientific method is an unproblematic set of rules which will result in the discovery of truth.
> **Thinking Carefully About Science**
> From our own experience as a group, we think you need to begin (the process of changing classroom practice) by considering the nature of science. Without this discussion you will lack the intellectual basis on which to formulate your practice. Nevertheless, expect this foundation to change and improve, as you try to put it into effect.

Box 9 Teachers' reflections on the nature of science (**2.5**)

The view of scientific process evolved by the Leicestershire group, is shown diagramatically in Fig. 2.

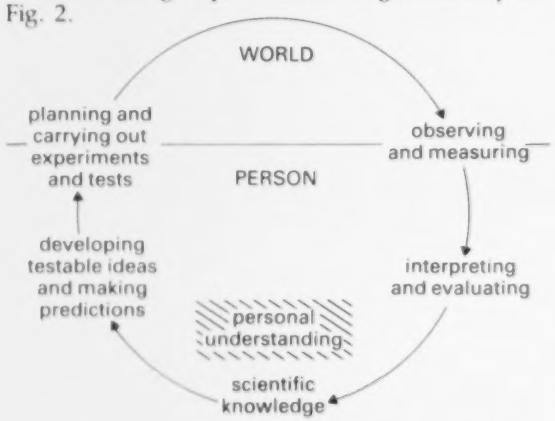


Fig. 2 How scientists find out about their world (**2.5**, p.4)

Having arrived at a set of views about science the obvious next step is to begin to translate these into practice in the classroom. The Leicestershire *Science Process* handbook (**2.5**), contains some useful 'experiments in teaching', some of which were described earlier in Section 3.

SECTION FIVE

Technology and science in the school curriculum

Setting the scene

> *Broad agreement is needed on what constitutes technology at the school level and how such work can best be introduced into the curriculum of all pupils.* (**5.1**, Para.4.1)

> *Links between teachers of science and CDT teachers are vital if a damaging and unnecessary division between science and technology is to be avoided.* (**1.1**, Para.57)

In much of the development work that has been undertaken by SSCR groups in order to make science more relevant to students' interests and needs it is apparent that there is a desire to introduce technology into school science. Some groups have been mainly concerned to enhance youngsters' **technological awareness;** the main aim of others has been to enable students of science to acquire **technological capability** (**5.2**) through participation in problem-solving exercises of the 'design-and-make' variety. In all cases the assumption is made that school science should have a technological component and that this ought to be substantial.

This assumption is highlighted in the Review's aims for school science (**3.3**): All youngsters should have opportunities:

> *to study the key areas of science and technology that relate to the world of work and leisure;*
>
> (to acquire) *an understanding of the part science and technology play* (in their society);
>
> *to design and develop solutions to technological problems.*

The DES, in its statement of policy (**1.1**, Para.57), makes it quite clear that it shares this view:

> *All science courses should have a technological content ... Courses need to be developed which foster the essential scientific content, skills and processes while at the same time providing opportunities for related technological work.*

Such is the precept. In practice, however, it is evident that school science curricula could do much more to foster *both* technological awareness *and* capability. In their report of an enquiry (from 1981–83) into technology work within science courses (**5.1**, Para.4.6) HMI state that:

> *Work of the highest quality was observed where the science taught was related to its applications in life generally and where pupils were helped and encouraged to use their knowledge to solve scientific and technological problems appropriate to their age and ability.*

In general, however, HMI express the view that science departments need to give greater attention to creating more opportunities for children:

- to identify and solve technological problems;
- to grow in their awareness and understanding of technology through their study of science.

Moreover the place of technology in school science is just one facet of a set of wider issues, namely, **whether, why and how technology education should be included in the curriculum of all young people** up to the statutory school leaving age. Doubtless many teachers and others concerned with the education system would subscribe to the view that youngsters should gain some knowledge and experience of technology at school in order to prepare them for life in a technological society. And yet, on questions about the **nature of technology** at school level and about **why and how it should be introduced** into the curriculum there appears to be no clear consensus (**5.1**, **5.3**).

Take, for example, the question of why there should be technology education up to the age of 16. Is the proper rationale for including technological studies in the school experience of young people essentially educational? Such would seem to be the view that has been expressed by HMI in recent years (**5.4**, pp.27-28):

> *Technology is therefore, first and foremost, a cultural study. As such, a course on technology merits consideration for a place in the curriculum of all pupils until the statutory school leaving age. ... A good technology course at the secondary level is not only a cultural study which involves children in technological activity. It is also a general preparation for any adult society; even one that favours alternative technology, as opposed to high technology and industrialisation.*

Alternatively, should the major reasons for introducing technological work into the school curriculum be vocational? The answer from the Technical and Vocational Education Initiative (TVEI), for example, would appear to be an unequivocal 'yes'. Education and training related to aspects of technology, especially 'new technology', have been important components of the TVEI experiment which aims to attract more 14–18 year olds to:

seek the qualifications/skills which will be of direct value to them at work ... (so that) ... they are better equipped to enter the world of employment which will await them. (**5.5**, p.34)

The SSCR view, that the case for technological studies for all students rests primarily on general educational grounds, relates to what has been said earlier, in Section 1, about the relevance of school science to young people's thinking and living, both present and future. We will now go on to consider:

- the nature of technology and of the relationship between science and technology;
- the place and role of technology in the science curriculum, and in the school curriculum in general;
- some examples of ways in which SSCR working groups have sought to develop children's technological capability and awareness through science.

What is technology and how does it relate to science?

Often it is difficult to distinguish between the pursuit of knowledge and the application of this knowledge. Technology and science interact. (**3.29**, p.9)

What do we mean by technology?

The word technology is commonly used in one of two rather general senses. Sometimes it denotes *an artefact* (a piece of technology, such as an automatic washing-machine), a *technique* or *process* (such as *in vitro* fertilisation) or *a system* (as in 'the technology of the motor-car'). In other instances technology is used to refer to *a human activity* – the process(es) whereby technological products are created. Often the word carries shades of both sorts of meaning as, for example, when we speak of students learning about aspects of technology that relate to medical care. This could mean, for example, learning about kidney dialysis technology (the machine and the principles on which it operates) or about the technological activity of which the kidney machine is the end-product. Clearly using the word technology in both these senses can be valid and appropriate. That having been said, it is our view that *technology as a human activity* is the more fundamental meaning.

But what sort of human activity is technology? The question is much easier to pose than to answer. Trying to define what we mean by technology is rather like trying to define a cow! Statements such as: 'A cow is the female of bovine animals'; or 'A cow is a domesticated milk-producer' are true enough but neither can be regarded as a wholly adequate description of this complex and variable living organism. In this respect (if in no other!) technology may be likened to a cow: it is something 'you recognise when you see it' (Sparkes in **5.6**).

> Technology is a disciplined process using resources of materials, energy and natural phenomena to achieve human purposes. (Cited in **5.7**)
>
> The ... central element in technology is problem-solving ... a disciplined process using scientific, material and human resources to achieve human purpose. (**2.1**)
>
> We shall define technology as that research where the main product is not a paper, but instead a machine, a drug, a product, or a process of some sort. (Price, cited in **5.8**)
>
> It is concerned with meeting human need or purpose.
> It is the control of the environment.
> It is the application of scientific and other forms of knowledge to the use of physical resources.
> It is a creative process of using human knowledge and physical resources to solve practical problems.
> (CDT teachers, cited in **5.4**)
>
> Technology is concerned with how people cope with their environment. It is about creating order out of disorder.
> (Science teacher, quoted in **5.9**, p.120)
>
> The essence of technology lies in the process of bringing about change or exercising control over the environment. This process is a particular form of problem-solving: of designing in order to effect control. (**5.10**, Para.34)
>
> Technology is the systematic application of scientific or other organised knowledge to practical tasks. (**5.11**)
>
> Technology is the application of scientific and other organized knowledge to practical tasks by organisations that involve people and machines. (**5.12**)

Box 10 *Some definitions of technology*

The list of definitions in Box 10 has been gleaned from an assortment of sources and gives some flavour of the variety of ways in which the technological process can be described. From these various interpretations we can list a number of characteristics of technology. It is concerned with:

- practical problems and tasks related to the desire to achieve some human purpose or to meet some human need;
- affecting or controlling the environment;
- producing an artefact (piece of hardware) or designing a process or system.

In addition:

- technology is a social activity; technological

work is usually team work;
- technology is a multi-disciplinary activity; technologists make use of knowledge and skills (both intellectual and manual) from a wide range of sources.

There are several further comments that should be made here. Firstly the human *purposes* which technological activity seeks to achieve may or may not fulfil human *needs*. The products of technology can be both benign and malign in their effects on humanity and the environment, and are often controversial.

Secondly, solving practical problems is an essential part of technological activity but, as the authors of a Scottish report on technology in the secondary curriculum point out, technological activity and problem-solving are not synonymous. Problems can be:

> *wholly theoretical; they may be practical only in the sense that they purport to deal with 'real things ... but do not require the pupil to construct, assemble or put a plan into practice; some problem-solving activities can ... involve pupils in part of the 'design and make' process* (**5.13**, p.10).

And thirdly, the idea, which some of the statements in Box 10 make more explicit than others, is that **science is an important source for technology but it is not the only one.** Contrary to popular opinion (as evidenced by the loose and interchangeable use of the terms science and technology by the media) and, perhaps, the perceptions of many of us who have been educated and trained in science, the picture of technology as applied science 'simply will not fit all the facts' (**5.8**). And yet there is a sense in which this image of technology is being perpetuated by our educational system. Indeed it is not difficult for children – and parents – to gain the impression that technology is equal to so-called 'high technology' and this in turn equals 'applied microelectronics', or just microelectronics!

Differences, similarities and interactions

What is the relationship between technology and science if the former is not merely the application of the latter? In our question we imply that science and technology *are* distinguishable to some extent. Although both are creative human activities, there are differences, for example, in the goals and methodologies of the two disciplines. We could distinguish between the goal of technological work, which is the production of a successful artefact or system, and of scientific research, which is the acquisition of new knowledge. Or we could differentiate between the constraints under which technologists and scientists operate (**5.14**):

> *The former works to a clear objective — usually defined, at least partially, by someone else (the customer). The scientist can change his objectives as his work progresses. The technologist must usually meet conditions relating to cost, time, etc., the scientist much less so.*

According to Sparkes (in **5.6**) the scientific approach to problems is essentially analytical; technological work involves synthesis as well as analysis.

However, none of these differences is clear-cut or absolute. Scientific research is certainly not purely analytical; the invention of hypotheses, for example, is a synthetic, constructive activity. Also, some scientific research (e.g., into novel chemical processes) is conducted as part of programmes whose overall aims are the development of a new product, or a better process by which to produce an old product (e.g., the work of chemists and, biologists in the pharmaceutical industry). Whether in an industrial or other context, scientists as well a technologists usually have to work within economic and time constraints.

In practice then there is a great deal of similarity between, and intermingling of, technology and science and it is not possible to make a sharp and neat distinction between them. The relationship between the two domains of enquiry can be partly represented by a simple diagram (Fig. 3) which indicates both the intersection and the dynamic interplay between the knowledge and activities associated with technology and science. The shaded area designates:

- the ways in which scientific knowledge and principles have been applied in the solution of technological problems; (we could call this applied science);
- the contributions that the products of technological activity make to scientific research.

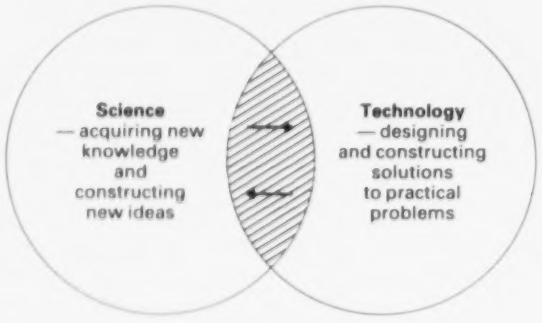

Science
— acquiring new knowledge and constructing new ideas
Technology
— designing and constructing solutions to practical problems

Fig. 3 The intersection of science and technology

The important point is that, instead of seeing technology as applied science with ideas flowing in one direction only, a symbiotic model of the science/technology relationship acknowledges that, whilst:

> *... technologists do, at times, make use of the findings and theories of basic science. ... it is equally true that scientists make occasional use of the ideas and artefacts of technology ...* (**5.15**, p.149)

But even this model of relationships between science and technology is too simple. Technologists apply technology as well as science. They also make creative use of other resources such as the principles and skills of craft, design and communication; aesthetics; they cope with economic constraints, and respond to cultural and historical perspectives (**5.7**, p.10).

Finally, as far as school science is concerned, the shaded area in Fig. 3 can be taken to represent both:

- the study of artefacts or processes that have resulted from the application of aspects of science; and
- the process of learning to apply science to the solution of technological problems.

Of course, as earlier discussions in Sections 1 and 2 have made clear, applying science means something wider than applying science for practical, including technological, purposes.

Why should technology feature in the school curriculum?

Before going on to consider ways in which technology ought to be incorporated into the school curriculum it is worth pausing to consider briefly why there should be school technology at all. Given that technology is an integral part of human culture and that knowledge, understanding and experience of technology are important for living in today's and tomorrow's world, it is evident that *all* pupils should have adequate opportunities to:

- learn about technology and its interactions with the individual, society and the environment;
- develop, through personal experience,the ability to engage in technological tasks.

As with school science the primary justification for having technology in the curriculum is *not* vocational. While there is a growing demand from employers for what are called technologically skilled people, we cannot agree that schools will best satisfy this demand by introducing new elements into the curriculum (of *some* children?) for largely vocational reasons. On the contrary, the Review's approach has been to emphasise the general educational value to all young people of better education 'in the area of science and technology' (**3.3**, p.13). Such an approach to the curriculum is entirely consistent with the need to provide a good basis for further education and training for particular forms of employment in industry or elsewhere (cf. Section 1). As one pair of authors (**2.1**) have put it:

> *providing a broad education for all students ... also makes the most appropriate and constructive base for young people to take with them into their particular form of employment, in which they can ... acquire the specific job-related skills required.*

There is evidence, from the response to the Review's consultative document (**3.3**), of industrialists concurring with this view (**5.16**). Furthermore, in his introduction to a recent collection of case studies of schools–industry links in the UK, Jamieson (**1.2**, p.2) cautions his readers against making the simplistic assumption that:

> *a vocationally oriented curriculum will maximise young people's productivity when they enter employment.* (In the United States) *... vocationalism has largely failed to meet the economic requirements of employers.*

How ought technology to feature in the school curriculum?

> *... there is a broad range of educationally valid and valuable activities which both cuts across boundaries of subject disciplines and ... needs to draw upon those disciplines and to feed back to them.* (**5.7**, p.24)

Introductory remarks

Whilst the main focus of this section has to be on technology in the *science* curriculum it is important that technology education through school science should not be seen in isolation from the curriculum in general. The interdisciplinary nature of technological activity ought to be reflected in the provision which schools make for technological education. Accordingly, we shall later present an approach to technology in the secondary curriculum that we would wish to commend to schools. Some of the practical organisational and timetabling implications of this model are considered in the SSCR guide **Better Science: How to plan and manage the curriculum.**

Some possibilities

What are the options for a school whose staff wish to introduce technology for all pupils up to 16? One set of answers to this question has been provided by members of the team which developed the Schools Council *Modular Courses*

in Technology. Five ways in which technology has been incorporated into the school curriculum are described in the *Teacher's Master Manual* (5.17) These are:

(a) *Technology as a single subject*: usually offered as a 4th and 5th year (examinable) option. Such a course may be based in the science or the CDT departments or involve teachers from both and is fairly easy to time-table;

(b) *Technological enrichment of existing subjects*: science and craft (craft-oriented CDT) in particular, but also other subjects such as home economics, geography and history. This approach 'makes least demands on existing time-tables and organisation' and can be used to develop awareness of 'the dependence of society on technology' especially in the early years;

(c) *Technology in general studies*: which would appear to be a useful vehicle for the promotion of technological awareness but does not do much to encourage technological capability;

(d) *The technology 'topic' approach*: where several departments 'link forces to develop a particular theme or topic'. Here technology is used as 'a unifying factor throughout the curriculum'. The problems with this approach are practical ones related to the strongly subject-based organisation of most secondary school curricula;

(e) *Technology through 'extensive and/or open-ended project work'*: which again presents practical difficulties for many schools, e.g., it is not easy to timetable. This approach tends to be strong on capability but rather weak on technological awareness.

In their consideration of the question 'Which Mode Should We Choose?' the authors of the handbook seem to prefer mode (a), though this is not made explicit. As well as having some important educational advantages, for example, a structured course enables pupils 'to learn about technology and industry as well as behaving as technologists', the technology-as-a-single-subject approach offers some pragmatic gains. For example:

> *it offers an examinable subject which gives it status in the sight of headteachers, parents, and local industrialists as well as pupils themselves.*

The Project team admits that a structured technology course can be criticised on several grounds:

- it tends to foster the acquisition rather than the application of knowledge;
- it gives a limited view of technology, emphasising the resources and restraints rather than the process;
- it is subject-based rather than skill-based and develops convergent rather than divergent skills.

However they feel that these criticism can be 'largely offset' by the inclusion of project work (mode (e) in the list above) since this will allow:

> *pupils to experience the technological process for themselves, providing they have developed the necessary skills in the work that precedes the project;*
>
> *decision-making skills to be developed and knowledge to be applied rather than acquired.*

Nevertheless, in our view, the introduction of technology as single subject (with or without project work) is unsatisfactory, certainly in the longer term, as a way of providing technological studies and activities for all 11–16 year old pupils. Short of supplanting other equally important parts of the curriculum, such as art, as an option a technology course can only be one which just some pupils take – and probably in years 4 and 5 only. Girls especially tend to choose subjects like biology, home economics or needlecraft where these are set against technology in the fourth year options (**5.1**, pp.16-17). There can also be problems due to poor co-ordination of teaching in a technology course and concurrent science courses. One Head of Science, expressing her views about some of the problems associated with technology as a separate subject (in 4th and 5th years), had this to say (**5.18**):

> *As a separate subject there are dangers:*
> *(i) The science department may assume all the technological 'bits' are being catered for – and so pupils see no real relationship between science and technology.*
> *(ii) Unless co-ordination (between the technology and science courses) is excellent there will be overlap. The modular course is the one I'm most familiar with – and there is much in it which is part of 'normal science'. What a waste of time if it's 'done' twice over!*

In their discussion of the technological enrichment approach (mode (b) in the list above) the Modular Courses team indicate that this is probably as acceptable as the single-subject approach, especially for pupils in the 9–13 age range. However there are, they believe, a number of very real dangers with this approach, including the possibility that:

> *in science and craft studies, technology can become confused with applied science and design and the pupils receive less than a rounded view of technological activity.*

Thus it would appear that a more radical model

for technology in the curriculum of all young people is called for.

A preferred approach to technology in the curriculum

The model for technology in the 11–16 curriculum of all students which we would strongly recommend includes aspects of several of the approaches which the Modular Courses Project team has enumerated. In our view technology should be in the curriculum in two respects.

1 Firstly, children should have opportunities to study technology *within various areas of the curriculum*, especially in science and CDT courses but also in couses in other areas (mathematics, home economics, English, history, and so on). In this way they would be able to learn about and engage in aspects of the technological process, acquire technological skills, and grow in their awareness and understanding of personal, social, economic and environmental effects on, and implications of, technology.

2 In addition, provision should be made in the school timetable for regular *interdisciplinary work on technological projects*, both short-term and longer-term. This type of activity would complement, draw upon and feed back into the resources of knowledge, skills and experience developed through technology studies in science, and CDT, and in mathematics, English, history and other curricular areas.

Both types of experience are essential if youngsters are to have adequate opportunities to develop their capability in the area of technology and to acquire a rounded view of technological activities. This is not to imply that the enrichment of the subjects element (1, above) is intended to develop understanding and awareness only; nor that the tasks element (2, above) will not encourage the growth of awareness as well as capability.

To some extent we would go along with recommendations made in a recent report by the Oxford Educational Research Group (OERG) into the uptake of technology in Oxfordshire schools. The authors of the report (**5.3**) have recommended that:

- technology should be taught to all pupils up to 16 'through science and CDT lessons, and, where appropriate, by teachers of both in consultation';
- it should be taught both;
  - (i) 'as a problem-solving process' (developing capability);
  - (ii) 'through consideration of the applications and implications of technological processes and products' (acquiring awareness).

This is very similar to the first element of our preferred model. It also mirrors the views expressed by HMI on the desirability of close collaboration between CDT and science teachers:

> *The best work was achieved when science and CDT departments worked together and the pupils were free to use all the expertise and facilities available. ... Such interdepartmental co-operation is not easily achieved, but as technology is a multi-disciplinary study employing skills and knowledge developed by many subjects, more attention needs to be given to co-operation between departments.* (**5.1**, Paras. 3.57 and 4.7)

Like HMI, the authors of the OERG report recognise the number of sizeable barriers that may be in the way of moves towards effective collaboration between science and CDT departments, even where good informal contacts and personal relations exist. For example, timetabling difficulties can hinder progress; physical distance between science and CDT rooms, and lack of time for proper discussion and planning are also cited by teachers as difficulties. Besides these practical barriers differences in the sub-cultures of the two departments can prove to be a stumbling block to co-operation with the teaching of technology. For example, whereas CDT teachers have tended to be more preoccupied with skills, science teachers have been more concerned about teaching principles and concepts (**5.19**, p.154). Science teachers do not tend to share CDT teachers' desire that products of technological activities should be well crafted (**5.19**, p.8). According to the research team, the key to overcoming such barriers:

> *lies in the development of a whole school curriculum policy in which the technology is clearly defined and has a place in the education of all pupils up to 16.* (**5.3**, p.2)

Clearly, if the above OERG recommendations were followed through in all schools considerable progress in technology education at secondary level would have been made. However, we wish to move the 'target' further along to a position which closely resembles that paved by Black and Harrison in their paper entitled *In place of confusion* (**5.7**). The model of technology education proposed by Black and Harrison is represented in Fig. 4, which depicts the interactions between 'resources' and 'technology tasks' in the development of 'full technological capability', or what the authors dub 'Task-Action-Capability'. This technological capability is regarded (perhaps somewhat confusingly!) as having three dimensions each of which (**5.7**, p.6):

> *represents a personal attribute of direct practical value in the real world:*
> **Resources** *of knowledge, skill and experience*

which can be drawn upon, consciously or subconsciously, when involved in active tasks.
Capability *to perform, to originate, to get things done, to make and stand by decisions.*
Awareness, *perception and understanding needed for making balanced and effective value judgements.*

These three clearly interact. To develop capability and awareness, experience of tackling tasks is essential. Through such tasks we learn to apply resources of knowledge and skill, for the mere possession of such resources does not imply or confer the ability to apply them. The relationship is mutual, for the needs of real tasks can provide a motive for acquiring new knowledge and skills or for consolidating those already learnt.

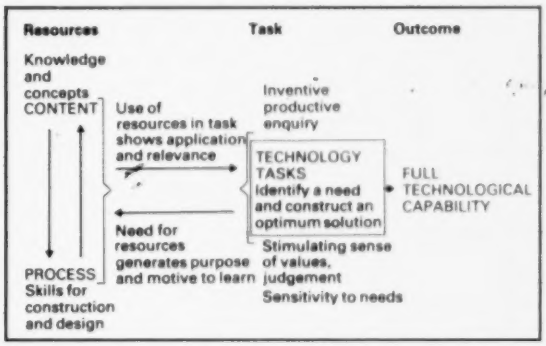


Fig. 4 A model for technology education (based on 5.7, p.7)

Black and Harrison propose that this approach to technology education, and a very similar model of science education, be incorporated into a model for the school curriculum (Fig. 5) which reflects the inter-disciplinary nature of technology tasks, and other types of tasks. Other subjects, as well as science and CDT (or possibly technology) have contributions to make to work on technological tasks.

The Review's preferred approach to technology education, as stated above, is clearly a variation on the Black and Harrison theme. In what is perhaps a simplified form, we are endorsing their argument that, in order for pupils to appreciate more fully the inter/multi-disciplinary nature of the technological process, they need to have opportunities to tackle tasks which will encourage them to use and extend what they are learning in science, CDT and other areas of the curriculum. There are two further important, and inter-related, points we would wish to underline:

1 We take it that none of the traditional subjects should be regarded as *only* a resource for use in tackling practical tasks. Science, for example, has other sorts of applicability, as we have argued in earlier sections.
2 Although the main focus of the Black and Harrison paper is on technology, their curriculum model indicates that inter-disciplinary tasks should not be restricted to technology projects. For example, staff from various school departments could collaborate to

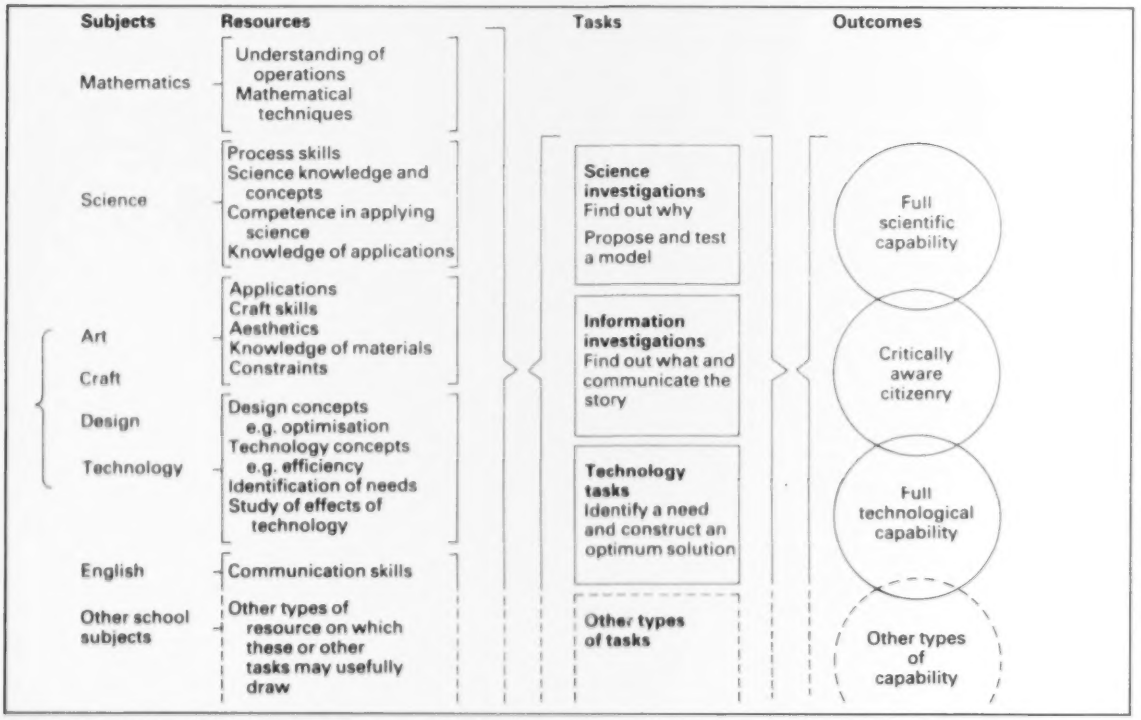


Fig. 5 A model for the curriculum based on 5.7, p.25)

provide pupils with opportunities to tackle projects on rural studies, on contemporary or local issues, on the history of science, technology or industry, and so on.

Some implications of the model

(a) *For science teaching*: In the final part of this section we will look in more detail at some of the ways in which SSCR working groups have endeavoured to 'technologise' school science. At this point it is worth emphasising that the technological content of a school's science provision (i.e., both knowledge and processes) should not, in our view, be limited to some aspects of physics.

(b) *For collaboration between teachers:* Careful planning within subjects and across subject boundaries and co-operative working among teachers would have to become the order of the day. In particular:

- it would be essential for science and CDT teachers to collaborate closely in the designing and teaching of their courses;
- teachers of subjects other than science and CDT would also need to take responsibility for making contributions to the technological awareness of pupils;
- teachers of science, CDT, English, mathematics, history, religious studies, etc., would have collective responsibility for work on inter-disciplinary tasks.

(c) *For curriculum structure and timetabling:* The model presupposes the existence of some sort of subject-based curriculum structure but requires the creation of a regular slot in the timetable for inter-disciplinary work. These timetabling and organisational implications are considered further in the companion guide **Better Science**: **How to plan and manage the curriculum**.

Obviously the curriculum model that we are proposing for school technology is idealistic; this does not imply that it is unrealistic. The practical and organisational problems that would be associated with realising the model are not insurmountable in the longer term, provided that, in secondary schools:

- there is an overall view of the curriculum in which technology is regarded as an integral part of general education; and
- there is a willingness to develop a collaborative, inter-disciplinary approach to technology education.

In the latter respect perhaps secondary teachers could learn from their primary colleagues. The case studies described in *Science in the Locality* (**3.29**) to which reference was made in Section 3 give an indication of what can be done in the secondary sector.

Current practice in school technology education

> *Another contributory factor to good quality work was close co-operation between the science and CDT departments which made available to pupils a wide range of expertise and resources...* (**5.1**, Para.4.7)

Some sources of information

Among the limited number of sources which we shall draw on for information about current practice are two recent HMI reports. One of these has sought to 'gain a better understanding of the form technology takes when it is part of the science courses offered to pupils' (**5.1**, p.2), and is based on a survey of 58 schools in England and Wales in each of which a course designated 'technology' was offered.

> *In every school the course was organised by the science department; in some instances staff from both science and CDT departments shared the teaching.* (**5.1**, p.3)

The other, slightly more dated, HMI report concerns the teaching of technology in CDT courses in 90 schools. Contributions by CDT teachers to 'technological studies which involved teachers from several disciplines, such as history and science' (**5.4**, p.4) are also described.

The Science and Technology Sub-Committee of the ASE have conducted a more recent survey of technology in schools and find that technology studies have 'a significant place in the curriculum of many schools'. The Sub-Committee also detected a trend towards greater co-operation between science and CDT departments (**5.20**). The results of a survey carried out by an SSCR group in Leicestershire of technology teaching in schools in their LEA indicate that, in approaching half of the schools where some kind of technology was taught, both science and design staff contributed (**5.9**, p.137).

Another useful source is the OERG report (**5.19**) to which reference has been made. This includes an account of the introduction of new teaching material for the 11–13 age range, case studies of five schools where a structured technology course was introduced, and a study of technology across the curriculum. Unfortunately only a summary of the main report is readily available (**5.3**).

Aspects of the general picture

There are many schools throughout the country where technology has been incorporated into the curriculum in some form or other. Partly this is due to developments in CDT teaching, where increasingly there have been moves away from

handicraft towards work on technology. This type of reorientation of CDT towards more emphasis on technological activities is being encouraged, for instance, by the influence of GCSE National Criteria on examination syllabuses. Increasingly, as McCormick puts it in one section of the new Open University Advanced Diploma course (**5.21**) on Technology in Schools, CDT has been assuming a major responsibility for technology.

> *But not everyone is happy with this. From the craft tradition is the fear of the loss of this tradition and the development of an over-academic approach; from the scientists is the fear that watered-down physics will be taught, in direct competition and without liaison.* (**5.21**, Section 1.5)

There has also been some reorientation of science courses towards technology, particularly the development of technological awareness. In addition, technology and applied science courses are being taught by science or CDT teachers, or sometimes collectively by teachers from both departments. Even the latter very desirable approach may not be without its problems (**5.21**, Section 1.5):

> *Even where a separate subject, Technology, is created in the curriculum with shared teaching, between say science and CDT or science and design departments, there are conflicts of approach.*

Nevertheless the HMI findings are that in the relatively few schools where good working links between science and CDT departments have been established 'the quality of the work observed was much higher than in those cases where co-operation was slight or non-existent' (**5.1**, p.7).

Regarding the content of social technology, HMI expressed two concerns. The first was that virtually all the technology work was related to aspects of physics and engineering; very little linked up with work on chemical or biological aspects of science courses. Secondly, it was noted that few of the lessons observed involved consideration of the social and economic implications of technology (**5.1**, p.26).

Technology for 11–14 year olds

The ASE survey findings suggest that there are few specific technology courses for younger secondary pupils and the majority of those surveyed considered that technology education was provided through CDT courses rather than through science (**5.22**). One important factor here may be the dearth of suggestions and course material for children in this age range (**5.19**, p.235). The valuable work that has been done by SSCR groups during the past few years should help to remedy this situation.

The HMI reports (**5.1**, **5.4**) indicated that there were only a few schools in their survey samples where technological work was a part of the educational experience of *all* children; 'technology courses have little foothold in the curriculum before the age of 14' (**5.4**, p.19). Where planned efforts were being made to develop courses, they tended to occur in the third year. A description of how this was done in one school is reproduced in Box 11.

Third year technology through interdisciplinary projects

In the second school the teaching of technology was achieved through interdisciplinary projects devised and organised by a small committee made up of teachers from the departments of European studies, mathematics, English, history, physical education, science and CDT. This particular activity formed one of a number the school had introduced in an effort to develop technology across the curriculum. Projects tackled recently included 'planning a new town', 'firearms through the ages', and 'crossing the Alps'. Much of the work was design-based leading to model making within which the precise science contribution was difficult to identify.

***Box 11** Interdisciplinary technology project* (**5.1**, p.14)

One of the short 'case studies' in the teachers' handbook produced by the Leicestershire SSCR technology group (**5.9**, pp.131-2) describes how technology teaching for 11–14 year olds has been developed in one school through members of science and design departments working together.

Technology for 14–16 year olds

Separate technology courses are being offered, as an option, in an increasing proportion of secondary schools. Project work is an important part of the great majority of these, with pupils being required to undertake either a series of small projects, or one major one, as a part of the assessed course work. HMI observe that, while much of this project work requires pupils to design and construct an end-product as well as making use of their science, difficulties can arise when no similar experiences have been provided in earlier years (**5.1**, p.23).

> *Despite the fact that few of the pupils had been faced with such demands by the end of the third year, few science departments attempted to provide pupils with opportunities to develop a progressive and systemic* (sic) *approach to solving technological problems which emphasised the importance of using scientific knowledge and processes in conjunction with the skills of design.*

Some schools did require the pupils to tackle a

series of mini-projects in the earlier stages of the course, with the effect that 'the quality of the pupils' final project work was good' (**5.1**, p.24). And, as we have observed already, the quality of youngsters' work on technological tasks is regarded by HMI as being greatly enhanced by the involvement of both CDT and science teachers in the technology teaching.

In conclusion ...

Are there signs that evolution towards multi-/inter-disciplinary approaches to school technology is proving to be possible in practice? The limited evidence on which we have drawn here suggests that, at least in the 11–14 range, this is beginning to happen. Where there is a will and enthusiasm ways can be found. The situation in years 4 and 5 is complicated by the options system, which means that many pupils have little or no opportunity to engage in technological work. The extent to which increased emphasis on technology in new GCSE syllabuses in science, CDT, home economics and other subjects will help to change things for the better remains to be seen. In addition there are the effects that TVEI is having, and will have as it spreads into more schools. The design and manner of implementation of TVEI programmes seems to vary widely throughout the country. Thus Saunders, in his evaluation report on TVEI implementation, has noted that, in many schools 'TVEI curricula are adapted to fit the general shape of already existing curricular arrangements' (**5.23**, p.6). On the other hand, in a minority of participating schools:

> *TVEI has provided an opportunity to revamp the whole curricular map of the 14–18 age range, involving changes in organisation, content, assessment and teaching approaches.*

One example of a more radical approach to technical and vocational education is the pilot scheme which is underway in several Staffordshire schools, and which aims to produce a complete shift in both the content and the methodology of the curriculum for 'all youngsters in a year group and not just selected cohorts'. The Steering Group of the Stafford Education Industry Project take a wide view of the term vocational (**5.24**, p.6):

> *It should certainly include learning experiences concerned with industry and commerce but it also needs to encompass experiences based on the community and to include opportunities for young people to develop awareness of themselves and others. In this context 'vocational' comes to mean 'preparation for life', and the inherent danger in the emphasis on science, technology and technical studies of creating a utilitarian curriculum is avoided by emphasising the role of the creative and expressive arts ...*

Thus, whilst we may have reservations about the strongly vocational orientation and motivation of TVEI at source (see sections above on *Setting the scene*, for technology and *Why should technology feature in the school curriculum?*) it may be that, set within an overall school curriculum policy, TVEI programmes will be able to contribute to a process of evolution towards general technological education for all young people up to the end of their compulsory schooling.

Developing technological awareness and capability through science studies

> *... awareness and knowledge of the relationship between science and technology should be included among the objectives of any science syllabus. The study of technological problems, at first as well as second hand, should be incorporated in syllabus materials.* (**5.1**, Para.64)

Finally we examine a few examples of ways in which SSCR working groups have been able to develop more technological versions of school science. Many of the ideas to which we shall refer are for problem-solving activities and are aimed at younger secondary students – most often those aged from 11 to 13. Not only does this help to do something about the dearth of suggestions for technology activities for use with this age range (**5.20**, p.235), but the implementation of ideas such as these in science lessons for 11–14 year olds should greatly facilitate efforts further to develop youngsters' technological capabilities in years 4 and 5.

Some of the Avon problem-solving exercises to which reference has already been made in Section 2, provide pupils with opportunities to design and make various products, ranging from a paper bag to a humane mousetrap. One problem asks the children to design and make an alternative to a mercury or alcohol thermometer (**2.7**).

A group in Leicestershire have created and compiled a large collection of ideas (over 50) for technology lessons for children up to the age of 14 (**5.9**, p.134), which are intended to

> *develop some measure of technological capability for all, and to provide a lead into further technology courses.*

Usually the children are asked to design, make and test an artefact; sometimes this is related to social implications or economics constraints. The task may be intended to help pupils to learn a scientific principle, or to teach them to apply scientific ideas, or both. For the most part the connections are with science work on mechanics, energy and electricity. In some cases a series of

projects on one theme, e.g., 'Structures', or 'Controlling energy', has been devised. One of the most significant features of the Leicestershire work is the fact that it has contributions from members of both science and design departments. As such it provides an excellent example of the benefits that can flow from close collaboration between specialists.

Another useful source of ideas for technological problem-solving work in science lessons, which is suitable for children in the junior/lower secondary age range, has been produced by the convenor of a Review group in Hereford and Worcester (**5.25**). This handbook for teachers offers a great deal of sound and practical advice for those who may be new to the problem-solving approach and illustrates how inexpensive design technology tasks can be related to children's learning of important scientific principles.

Cambridgeshire teachers have developed a collection of problems requiring various amounts of time, some of which are suitable for pupils in year 4. An example is reproduced is Box 12.

The Lamp Problem YEAR 4

You must design a device that will light a 1.5V lamp.
Your device must have an on/off switch and work without you touching it.
You may not use a battery or mains electricity. You can use any apparatus in the lab.
When you have produced your device write a 'sales report' detailing how it works and why you think it is the best design.

***Box 12** A problem with a variable time allowance* (**5.26**)

A module on *Medical technology* prepared by a group in Newcastle, for use with 13–16 year old pupils, is an interesting example of how human biology can be related to the development of both technological capability and awareness. In the *Teachers' Guide* (**3.2**, p.1) the authors of the material have this to say about the technological problem-solving exercises:

> *How this is approached will obviously vary according to the circumstances and resources of your school. In some instances pupils may actually get to design and experiment practically with simple model systems. In others they may at least be allowed the opportunity to reason out theoretical solutions to simple problems.*

'How can dialysis be made quicker and more efficient?' is one of the problems posed in a study of kidney dialysis technology. Another concerns the design of a replacement heart valve (Box 13). The Newcastle material also points to ways in which moral, ethical and economic aspects of the science and technology being taught can be aired and discussed 'in a sensitive and well-informed manner'.

Extension 1 *EX1A*

Designing a Replacement Heart Valve

Put yourself in the position of one of the early "medical engineers".
You have the job of coming up with an idea (or lots of different ideas) for an artificial heart valve.
Before you start you need to know one or two things about what will be required–the design features. These are that the valve should:
1. be small enough to fit into the space inside the heart.
2. be able to be sewn in quite quickly and easily (remember that the 'seating' of the valve will gradually heal into the heart tissue and become completely leakproof).
3. be opened and closed simply by the flow of blood.
4. have as few moving parts as possible (so it will be long-lasting and won't require servicing).
5. be made of materials that will
   (a) present smooth surfaces to the blood (preventing damage to blood cells and reducing the build-up of deposits)
   (b) avoid 'rejection'.

You may want to work in a small group so that you can 'bounce' your ideas off other people, or do this for them. Do you study Design Technology? Even if you don't, why not talk to a teacher of this subject about the problem facing you?

***Box 13** A technological problem-solving exercise* (**3.2**)

SECTION SIX

Biotechnology in the school curriculum

This final section consists of an article written by **David Ingleby** (Head of Biology, Camborne School, Cornwall). It is a very appropriate way to end this curriculum guide, for several reasons:

1 As we have remarked earlier, much that passes for technology studies in schools is heavily biased towards physics — especially mechanics and electronics. As Black and Harrison have expressed it (**5.7**, p.13), technology is:

> *in danger of being defined as the sum of Civil, Electrical, and Mechanical Engineering so restricting its appeal and obscuring its true importance.*

Focusing on biological and, to some extent, chemical aspects of technology helps to redress the balance.

2 By concentrating on biotechnology studies the article highlights an important strand of the development work that Review working groups have been undertaking.

3 It brings together a number of the themes that have been raised in earlier sections, for example:
- the use of both problem-solving and various human contexts to help make school science more relevant to pupils;
- the fact that distinctions between science and technology so easily become blurred in practice.

4 Finally, and by no means of least importance, the article has been written by a practising teacher who has been actively involved with the Review. This should serve to underline the point that this Curriculum Guide as a whole has attempted to reflect development work throughout the SSCR network and, in that sense, aims to speak for practitioners to practitioners.

Why should biotechnology studies be in the school curriculum?

Although the word is a relatively recent invention, the area of human activity which biotechnology denotes is both ancient and modern. Biotechnology finds application in a great variety of industries, including those of food, agriculture, pharmaceuticals, energy and environmental control (**6.1**). Some of these are long established industrial processes, such as brewing, bread-making or pickling; others have been developed more recently as a result of advances in biological science and technology, e.g. insulin production and plant cloning.

There is value in youngsters being made aware of the wide range of applications of microbiology principles and of biotechnology processes. However, the educational value of biotechnology studies is not (and should not be) confined merely to details of the technical processes involved. The area labelled biotechnology provides an excellent illustration of the symbiotic relationship between science and technology (Section 5; **6.2**, p.104). Moreover, all types of biotechnology have contemporary significance; some have the potential to transform societies. A notable example is genetic engineering with its potential for use in the production of medicines or weapons for mass destruction.

Consequently studies of biotechnology can afford opportunities for pupils to consider the relationships between science, technology, industry and society generally. In studying such relationships we are inevitably drawn into considering the status of scientific knowledge itself. Biotechnology, then, presents an opportunity to explore a wide range of concerns across traditional curriculum boundaries.

Fitting biotechnology into the school curriculum

No one is suggesting that biotechnology should be taught as a fully fledged subject on a par with a separate science. For example, the Royal Society view (**6.3**) is that

> *aspects of biotechnology be introduced wherever possible into biology, chemistry, and physics syllabuses.*

An ASE working party has suggested specific ways in which biotechnology themes might be treated in GCSE biology, chemistry and science courses (**6.4**). Thus, as part of the treatment of cell biology, reference might be made to single cell protein manufacture. Reproduction could include practical work on cloning. In a chemistry or science syllabus, the topic energy and fuels could include gasohol. Work on the economics of chemical processes could include a comparison of enzymes with conventional catalysts.

The problem with this kind of approach, however, is that the biotechnology aspects could become yet more 'applications', tagged onto 'pure science' topics and devoid of any context that is meaningful for students.

There are other ways in which biotechnology can be incorporated into existing subjects and curriculum structures.

(a) Biotechnology can be included, as an option, in a technology course. For example, the WJEC GCSE Technology syllabus has a module on biotechnology which was developed by a Review group in South Wales (**6.5**). The intention is that the considerations involved when life processes are used in large-scale manufacturing be studied via case studies of one or more local industries.

(b) Project work, such as that indicated by the GCSE National Criteria, which could give scope for genuinely creative work by students and involve collaboration between different school departments.

(c) Biotechnology modules can be incorporated into TVEI schemes (e.g., **6.6**, **6.7**) or CPVE courses (**6.8**).

Our main focus here is on the efforts which several SSCR groups have made to encourage teachers to include aspects of biotechnology in their science curricula with a view to achieving one or more of the aims of:

- promoting awareness about the range of biotechnologies;
- promoting awareness of how the results of research in chemistry, biology and biotechnology are adopted by industry;
- promoting awareness of how science, technology and society interact;
- promoting scientific and technological capability.

Promoting awareness about the range of biotechnologies

An encyclopaedic knowledge of today's industrial applications of biotechnology is of limited use to the citizens of tomorrow. However, some appreciation of the nature of biotechnology and the basic science involved in its applications will be most important.

To this end an SSCR group in Staffordshire (**2.16**) has included, in their resource document for teachers, an excellent review of key biotechnological industries, and detailed introductions to each of five aspects of biotechnology, as background information for teachers who may be unfamiliar with the area. This information could be used for the preparation of suitable student materials in a school. The source book that an SSCR group in Wiltshire has produced contains practical activities from which teachers can 'select and adapt ... to enhance or bring a new approach to topics in existing syllabuses' (**6.9**).

One way of helping students to appreciate the nature of a particular biotechnology is to construct comprehension exercises which actively involve the students in learning through reading. The teaching materials produced by another SSCR group in Sheffield (**3.6**) include a number of directed reading activities. For example, students are asked to analyse, and produce a flow-chart from, a passage on the technical details of commercial yoghurt manufacture. The teacher here becomes a consultant to the groups, offering help as required.

Promoting awareness about how industry adopts the results of science and technology research

Biotechnology offers many opportunities for students to explore the workings of industry and the relationship between science and industry. Acquiring some appreciation of how industry adopts the results of scientific research can contribute to the development of understanding about the interactions of science, technology and society. Although industrial visits may stimulate interest and give students a feel for the scale of industrial processes, viewing fermenter vessels, control panels and valves will not, of itself, help them to appreciate how companies adopt new technology.

An interesting example of how this type of issue can be approached in the classroom has been developed by a group of South Yorkshire teachers. This is a case study which explores some of the wider issues involved in an real-life example of how one company solved an industrial problem (**6.10**). The problem was that the company faced a huge increase in water rates due to their disposal of large quantities of sugar into the sewage system. One exercise in the case study involves students, working in small groups, playing the roles of company directors. They consider the actual financial projections for building a fermenter which converts waste sugar into single-cell protein and the costs of labour, fuel and waste disposal. Decisions have to be made about employing personnel and whether to continue to treat the waste sugar if effluent charges were to be reduced. The exercise thus explores the role of profit, the conduct of industrial relations in industry, and the care of the environment by large corporations.

Promoting awareness of how science, technology and society interact

In solving industrial problems, biotechnology has raised a host of other problems and issues. Thus it can present useful opportunities for students to explore societal effects upon, and implications of, science and technology. The Staffordshire *Biotech* material (**2.16**) includes details of several instances

where technological and associated scientific advances have raised issues of public concern. The five case histories which are presented all concern genetic engineering and provide useful starting points for classroom learning activities such as discussion, role-play, brainstorming and comprehension exercises with appropriate texts.

The Sheffield SSCR material (**3.6**) includes a number of illustrations of ways in which controversial issues surrounding the application of biotechnology may be treated in the classroom. One of these focuses on the use of **cloning** to produce high yielding palm oil trees. Traditional methods result in many poor yielding specimens, but research into the new technology has resulted in clones (produced in the UK) being used in Malaysian plantations to increase yields. After being shown the stages of the process from the start of a plantlet in the UK to a mature tree in Malaysia on slides, the students are asked to assess the extent to which various groups of people have benefited.

In another study the students look at the implications of **genetic engineering**. Of all the branches of biotechnology, this is probably the most controversial. The techniques of genetic engineering involve the hereditary material of an organism being permanently modified so that a new substance or substances can be mass produced. As with cloning the public is still poorly informed, but during the 1970s a debate of sorts took place between scientists and community leaders about how far research into genetic engineering and its applications should be limited in the face of general public concern.

The Sheffield Group has developed resources which follow the history of insulin production by bacteria for the treatment of diabetics. As a scene setter students participate in a small play in which the treatment of diabetics is shown. A further historical treatment is given in materials which trace the development of bacterial human insulin production from the initial scientific breakthrough to the commercial sale of a product by an American corporation. Through a series of articles, based on actual newspaper and magazine extracts, the students build up a history of main events over a decade. They are also led to identify issues as reported by the press which the new technology brought to the fore. These include concern about the dangers of the new technology, the role of government in regulation of research, the links between industry and university researchers, and the role of trade unions.

Promoting scientific and technological capability

Much of the SSCR biotechnology material provides ideas for practical and investigational work. For example, an exercise on finding out consumer preferences can be used to improve students' abilities to design experiments (**3.6**).

Also, through work on biotechnology, students can have opportunities to design and develop solutions to technological problems. Scientific investigation has a central contribution to make in the carrying out of many of the technological tasks described or suggested in the SSCR biotechnology materials available at the time of writing. Thus many of the problems proposed in sections of the Staffordshire resource material would be more accurately described as scientific investigations than as technological design-and-make problems. Nevertheless there is much scope here for framing meaningful and manageable technological tasks in such areas as: enzyme technology, plant tissue culture, food technology and environmental protection technology. Some of these tasks could be undertaken in an interdisciplinary manner along the lines suggested by Black and Harrison (**5.7**).

In the SSCR contribution to the Walsall TVEI modular course (**6.6**) students learn about some of the scientific and economic factors which limit the scaling up of pilot investigations. Students carry out a long-term culturing exercise with single cell green algae. This sort of work could lead on to consideration of how conditions for various industrial processes can be optimised. For example, given that yeast can be made to produce alcohol and carbon dioxide, or to increase its biomass, or to degrade carbohydrate, groups of students could be given the task of determining which of these activities could be carried out most profitably by a local 'new start' company. Armed with their knowledge of model fermenters, each group could investigate one of the yeast processes, with the findings on different processes being pooled. The research might involve further work, with help from the CDT department, on the design and construction of the fermenter. Microelectronics could contribute towards monitoring and operation of the pilot plant. Yields, economics and marketing would need to be considered.

Technological capability is not just about mobilising intellectual and physical resources to solve a particular problem. The task outlined in the previous paragraph would require students to be aware of and to make decisions within realistic economic and social contexts. In addition providing students with opportunities to select and define tasks also contributes to their capability.

Other examples of biotechnologies from which suitable tasks could be developed are suggested in the Staffordshire handbook (**2.16**). These include:

- improving the set on yoghurts (the context could be commercial);
- speeding up the breakdown of detergents by

soil microbes (the context could be environmental pollution);

- producing silage more efficiently; or producing cauliflowers by cloning (the context could be agricultural economics).

This sort of fairly open-ended project work has important implications for the management of both students and materials. The classroom becomes more of a resource area, with students making decisions about the organisation of a task. The teacher increasingly becomes an adviser and organiser of material and information resources.

A project on washing powders put together by the Sheffield Biotechnology Group illustrates how short-term scientific projects might be organised. First the class is invited to develop, in small groups, hypotheses about the performance of biological as opposed to non-biological powders which they would like to test. Suggestions about investigating factors such as temperature or stirring can, if necessary, be offered by the teacher. Each group develops its own hypothesis, plans a project lasting several lessons and then fills in a planning sheet which it discusses with the teacher. A small resource area provides the materials needed.

Such an approach may be developed so that a whole series of different studies might engage different small groups within one class. The resource area, however would have to become much more extensive and technician support would need to be increased. Information sources would need to be more sophisticated, and the organisation of project monitoring more elaborate.

In conclusion ...

The value of biotechnology as a source of contexts for the promotion of capability, and for the development of awareness of the personal implications and societal interactions of technology and science, should be evident to readers (see **6.2**). What should also be evident is that it is possible to construct a variety of learning activities for a given piece of subject matter. Indeed in this, as in other areas of school science, it is essential to devise and try out alternative approaches to teaching to supplement traditional talk and chalk and verification practicals. Otherwise we will merely be transmitting to pupils a body of apparently immutable knowledge of science and technology.

Many of the classroom activities described here make fresh demands on both students and teachers. Students need to be actively engaged in learning if they are to acquire an

> *insight into the nature and meaning of biotechnology ... (and) ... its relevance in today's technological society*
>
> (**3.6**; Teachers' Introduction, p.1)

and if they are to begin to appreciate and express a diversity of viewpoints on issues associated with the use and development of science and technology. This may require major changes in the role of teachers. Rather than being *the* source of knowledge with the correct solutions to set problems, teachers become organisers of resources, consultants and just one of a number of sources of information and ideas. Though the demands are considerable, a more collaborative relationship between teacher and students can make for more rewarding and enjoyable experiences for both.

SECTION SEVEN

Summary of recommendations

1 Efforts should be made to ensure that school science is perceived by youngsters to be:

- **relevant** to them in their present and future lives;
- **applicable** by them in their construction of personal understandings of themselves and the world they inhabit, and in solving practical problems.

2 Students' experiences in school should be such as to enable them to appreciate the **humanness** of science and technology. Specifically, they should have opportunities to learn that:

- science and technology are creative and potentially enjoyable human activities in which they can participate;
- scientific ideas are provisional and often controversial;
- both science and technology are affected by the social and historical contexts in which they develop;
- validity is not the exclusive possession of contemporary European technologies or scientific explanations which have their roots in Western European culture;
- the effects of applying science and technology can be both benign and malign.

3 In order to achieve these first two objectives school science should:

- relate, as far as possible, to the ideas, interests and real-world experiences of individual students;
- be presented in human contexts, both contemporary and historical;
- encourage youngsters to consider and discuss human problems and issues connected with the application of science and technology in society;
- provide opportunities for pupils to engage in investigative and technological problem-solving activities that are open-ended to various degrees.

4 **Technology studies** should feature in the curriculum of all pupils of compulsory school age, but not necessarily as another separate subject.

5 Technological work in science should reflect the importance of chemistry, biology and other sciences as well as physics.

6 The *multi-disciplinary* nature of **technological activity** ought to be reflected in the provision which schools make for technological education. Thus, we recommend that:

- aspects of technology should be an integral part of science, CDT and also of other areas of the curriculum:
- in addition, provision should be made in the school timetable for regular interdisciplinary work on technological projects.

7 There should be much more **collaboration** than is often the case at present between the science department and other departments. This could involve:

- co-ordination of courses in science with those in the humanities, mathematics, and home economics, etc.; and
- contributing to a variety of interdisciplinary projects.

Such collaboration is essential if young people are to perceive the personal relevance and interrelatedness of all aspects of their experience of secondary schooling.

References

The SSCR publications referred to under the series title **Better Science** are not listed here.

0.1 Ebbutt, D. and Watts, D.M. *Science is Like a Spider's Web? Some Six Formers' views of their science education 11–16*, ASE, Hatfield, for SCDC Publications, 1987

1.1 DES *Science 5-16: A statement of policy*, HMSO, 1985

1.2 Jamieson, I. *Industry in Education: Developments and case studies*, Longman for SCDC Publications, 1985

1.3 Rolls, I.F. Quality and the education and training of future teachers of science, *School Science Review*, Vol. 67, pp.5-12, 1985

1.4 Schollum, B. and Osborne, R. 'Relating the new to the familiar', in Osborne, R. and Freyberg, (eds), *Learning in Science: The implications of children's science*, Heinemann, 1985

1.5 Newton, D.P. 'Tempered with humanity', *The Times Educational Supplement*, 18 April, 1986

1.6 *The New Scientist*, No. 1510, p.17, 29 May 1986

1.7 The Royal Society. *The Public Understanding of Science*, 1985

1.8 Head, J. *The Personal Response to Science*, Cambridge University Press, 1985

1.9 Roberts, W. and Sutton, C.R. 'Adults recollections from school chemistry – facts, principles and meaning', *Education in Chemistry*, Vol. 21, pp.82-85, 1984

1.10 Bell, B. *The Construction of Meaning and Conceptual Change in Classroom Settings: Case studies on plant nutrition*, University of Leeds, 1985

1.11 APU. *Science in Schools. Age 15: Report No. 2*, HMSO, 1984

1.12 APU. *Science at Age 15*, HMSO, 1985

1.13 APU. *Science at Age 13*, HMSO, 1984

1.14 Driver R. 'Students' thinking and the learning of science: a constructivist view', *School Science Review*, Vol. 64, 443-456, 1986

1.15 Osborne, R. and Freyberg, P. *Learning in Science. The Implications of Children's Science*, Heinemann, 1985

1.16 Bell, B., Watts, D.M. and Ellington, E.C. *Learning, Doing and Understanding in Science: The proceedings of a conference*, SSCR, London, 1985

1.17 Driver, R., Guesne, E. and Tiberghien, E. *Children's Ideas in Science*, Open University Press, 1985

1.18 Brook, A., Briggs, H. and Driver, R. *Aspects of Secondary Students Understanding of the Particulate Nature of Matter*, University of Leeds, CLISP, 1984

1.19 Brook, A. and Driver, R. *Aspects of Secondary Students Understanding of Energy*, University of Leeds, CLISP, 1984

1.20 Bell, B. and Brook, A. *Aspects of Secondary Students' Understanding of Plant Nutrition*, University of Leeds, CLISP, 1984

1.21 Terry, C. 'Physics, relevance and understanding', *School Science Review*, Vol. 67, pp. 143-5, 1985

2.1 Woolnough, B. and Allsop., T. *Practical Work in Science*, Cambridge University Press, 1985

2.2 Swift, D. G. *et al. Problem Solving for Science Classes*, Huddersfield Polytechnic, 1986

2.3 Logan, J. *Organizing Investigative Science (11-13)*, Northern Ireland Council for Educational Development 1986

2.4 Screen, P. *An Introduction to Process Science*, Warwick Process Science Project, 1984

2.5 Leicestershire Education Authority. *Science as Process: Encouraging the scientific activity of children*, 1985

2.6 SSCR. *Doing Problem-Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.7 Sage, J. *et al. Problem Solving in Science 11–13*, County of Avon, 1986

2.8 Johnsey R. *et al.* 'Flight – a problem solving approach' in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.9 Wiltshire County Council: *Problem-Solving A teacher source book*, 1986

2.10 Leat, C. *et al. Links. Problem Solving Guidelines and Activities*, Northamptonshire County Council, 1986

2.11 Nott, M. 'Problem Solving in School Science' in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.12 APU. *Science Assessment Framework: Age 13 and 15*, HMSO, 1984

2.13 Munson, P. 'Some thoughts on problem solving', in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.14 Heaney, J.C. 'Performing problem solving', in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.15 Leicestershire Education Authority. *Basic Needs of Industry and Science in Schools*, 1985

2.16 Staffordshire Education Authority. *Biotech*, 1985

2.17 Hampshire Education Authority. *Electronics* (no date)

2.18 Hampshire Education Authority. *A Short Electronics Course for Third Year Pupils* (no date)

2.19 Essex County Council. *Primary Approaches to Secondary Science*, 1984

2.20 APU. *Science in Schools. Age 13: Report No. 2*, HMSO, 1984

2.21 Reay, J. 'Scientific investigation in our science teaching', cited in Woolnough, B. and Allsop, T. *Practical Work in Science*, pp.53-54, Cambridge University Press, 1985

2.22 Wellington, J.J. 'What's supposed to happen, sir?', *School Science Review*, Vol. 62, pp. 167-73, 1981

2.23 Driver, R. *The Pupil as Scientist?*, Open University Press, 1983

2.24 Chalmers, A.F. *What is This Thing Called Science?*, Open University Press, 1978

2.25 Barker, M. *et al.* 'Problem-solving for the less able', in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.26 Cambridgeshire Education Authority. 'Problem-solving' in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

2.27 Holroyd, C. 'What is a problem? What is problem solving?', in *Problem Solving: Is there a problem?*, Royal Society of Chemistry, 1985

3.1 ASE. *Rethinking Science? Teaching science in its social context*, ASE, Hatfield, 1984

3.2 Newcastle SSCR Group. *Medical Technology: A science teaching module* (in preparation)

3.3 SSCR. *Science Education 11-16: Proposals for action and consultation*, SSCR, London, 1983

3.4 Belfast SSCR Group. *Health Aspects of Microbiology*, Northern Ireland Council for Educational Development, 1986

3.5 Belfast SSCR Group. *The Genibug Kit. Approaches to the Teaching of Genetics*, Northern Ireland Council for Educational Development, 1986

3.6 Sheffield SSCR Group. *Biotech*, ASE, Hatfield, 1987

3.7 Smith, M. *et al. Science in the Home: Electricity* (in preparation) (North Tyneside SSCR Group)

3.8 Leicestershire Education Authority. *Science Education for a Multicultural Society*, 1985

3.9 Elliot, L. *et al. Separation of Mixtures*, Cleveland Education Authority, 1986

3.10 Mullan, T. *Metals at Work*, Northern Ireland Council for Educational Development, 1986 (a 10 minute video recording)

3.11 Newcastle SSCR Group. *Man and the Enviroment* (in preparation)

3.12 ASE. *Rural Science: An applied view of science*, ASE, Hatfield, 1984

3.13 Hereford and Worcestershire County Council. *Rural Science* (in preparation)

3.14 Browne, N. *Geology in the Secondary Science Curriculum*, 1984 (unpublished discussion paper for Belfast SSCR group)

3.15 Eyles, P. and Fisher, J. *Earth Science as an Integral Part of a Balanced Science Curriculum*, University of Bath, 1985 (materials for use with INSET Courses)

3.16 Browne, N. *Science Down to Earth*, Northern Ireland Council for Educational Development (in preparation)

3.17 Allsop, T. 'Geology in the school science curriculum, *Education in Science*, pp.26-27, June 1983

3.18 Newcastle SSCR Group. *Let's Look at Rocks* (in preparation)

3.19 S. Wales SSCR Group. *Topics in the History of Science and Technology*, ASE, Hatfield, 1987

3.20 Stone, P.J. 'Industrial History in the Chemistry Syllabus', ASE, Hatfield (in preparation)

3.21 Baxter, J. *Astronomy in Science* (in preparation)

3.22 Stewart, D. 'Why should historical aspects of science and technology be part of school science?', ASE, Hatfield (in preparation)

3.23 Kent Education Authority. *Problem Solving 11–14* (no date)

3.24 Holman, J. *Science and Technology in Society: General guide for teachers*, ASE, 1986

3.25 McKim, F.R. (ed.) *Physics Plus*, Hobson/SCSST, 1985/86

3.26 McKim, F.R. 'The Physics Plus Project,' *Physics Education*, Vol. 18, pp.221-4, 1983

3.27 *Salter's Chemistry*, Science Education Group, Department of Chemistry, University of York, 1987

3.28 Harding, J. and Donaldson, J. 'Chemistry from issues', *School Science Review*, Vol. 68, pp.48-59, 1986

3.29 Jennings, A. *Science in the Locality*, Cambridge University Press, 1986

4.1 Solomon, J. 'Motivation for learning science', *School Science Review*, Vol. 67, pp.437-42, 1986

4.2 Powell-Davies, T. A. *Using Historical Approaches to Improve the Secondary Pupil's Image of Science*, Dissertation, Cambridge University, 1986

5.1 DES. *Technology and School Science: An HMI enquiry*, HMSO, 1985

5.2 Ditchfield, C. 'Technology and the applications of science', in *Science and Technology Education: Issues from a conference*, pp.37-43, SSCR, 1985

5.3 Nash, M., Allsop, T. and Woolnough, B. *Factors Affecting the Uptake of Technology in Schools*, Department of Educational Studies, University of Oxford, 1984

5.4 DES. *Technology in Schools*, HMSO, 1982 (developments in CDT departments)

5.5 Manpower Services Commission. *TVEI Review 85*, 1985

5.6 SSCR. *Science and Technology Education: Issues from a conference*, SSCR, London, 1985

5.7 Black, P. and Harrison, G. *In Place of Confusion. Technology and Science in the School Curriculum*, Nuffield-Chelsea Curriculum Trust, 1985

5.8 Price, D. J. de S. 'The parallel structures of science and technology', in Barnes, B. and Edge, D. (eds) *Science in Context*, Open University, 1982

5.9 Leicestershire Education Authority. *Technology 10–14. A Teachers' Guide*, 1985

5.10 DES. *The Curriculum from 5 to 16*, Curriculum Matters 2, HMSO, 1985 (an HMI series)

5.11 McCloy, D. *Technology Made Simple*, Heinemann, 1984

5.12 Open University. *Living with Technology. A Foundation Course*, T101 Introductory Unit, 1981

5.13 Committee on Secondary Education (COSE), *The Place of Technology in the Secondary Curriculum* (A discussion paper), Dundee College of Education, 1985

5.14 Brown, J., Director of GEC University and Schools Liaison (personal communication, 20 March, 1986)

5.15 Barnes, B. and Edge, D. (eds) *Science in Context*, Open University, 1982

5.16 SSCR. *Science Education. Responses to the Consultative Process*, SSCR, London (in press)

5.17 Page, R., Poole, J., Hucker, J. and Harris, D. *Modular Courses in Technology — Teacher's Master Manual*, Schools Council, 1981

5.18 Hannon, M., Head of Science, Piggott School, Reading (private communication; no date)

5.19 Nash, M., Allsop, T. and Woolnough, B. *An Investigation into the Factors Affecting the Uptake of Technology in Schools* (A report to the DES, 1984), Department of Educational Studies, University of Oxford, 1984

5.20 ASE. From the Science and Technology Sub-Committee, *Education in Science*, No. 114, p.16, September, 1985

5.21 McCormick, R. *Technological Education*, part of OU Advanced Diploma in Technology in Schools, Open University, 1987

5.22 ASE. 'Report from Science and Technology Sub-Committee (in preparation) (Some findings from this report have been published in *Education in Science*, pp 27-28, November, 1986)

5.23 Saunders, M. *Emerging Issues in TVEI Implementation*, Institute for Research and Development in Post Compulsory Education, University of Lancaster, 1986 (unpublished report)

5.24 Staffordshire Education Industry Project. *This is the Way*, 1986

5.25 Johnsey, R. *Problem-Solving in School Science*, Macdonald Education, 1986

5.26 Howlett, A. 'Problem-solving and the art of teacher maintenance', in *Doing Problem Solving: A collection of ideas and approaches*, SSCR, London (in press)

6.1 Stoker, A. 'Biotechnology – the need for schools involvement', *School Science Review*, Vol. 64, p. 435, 1983

6.2 Wymer, P. in *Science and Technology Education: Issues from a conference*, SSCR, London, 1985

6.3 The Royal Society. *Biotechnology and Education: The report of a working party*, 1981

6.4 ASE. 'Biotechnology in science examination syllabuses', *Education in Science*, No. 111, p.16, January, 1985

6.5 *Background Biotechnology* (A series of booklets for teachers; titles: *Yesterday, Today, Tomorrow – an Introduction; Genetic Engineering; Industrial Use of Microbes; Metabolism and Enzymes; Food and Energy*), University College Cardiff (in preparation)

6.6 Walsall TVEI. Modular Scheme. *Industrial Science: Biotechnology module*, 1985

6.7 Wigan TVEI.*Modular Science*, 1985

6.8 Barclay, A.C. and Edees, R.E. *Biotechnology*, Coventry Education Authority, 1986

6.9 Wiltshire County Council. *Biotechnology: A teacher sourcebook of experiments and evaluations*, 1985

6.10 Sheffield Education Committee. *Food from Waste*, 1985

The Secondary Science Curriculum Review (SSCR) was set up in 1981 to stimulate, through working groups of practising teachers, the development of science studies which would help to provide an appropriate science education for *all* young people growing up in a scientific and technological society — whatever their abilities or career intentions. Its concern was not only with the science curriculum — its contents, purposes, teaching methods and resources — but also with the role of science in general education and within the whole school.

The **Better Science: Curriculum Guides** are based on the combined experience of the Review's Central Team and the working groups. Each Guide deals with a different but significant area of concern. Together they aim to assist teachers both in devising a broader and more balanced approach to science studies and in enhancing their professional development. The intention throughout is not necessarily to provide answers but rather to provoke and encourage teachers' thinking about the various topics addressed.

This Guide, **Better Science: Making it relevant to young people,**

- draws together examples of work from a variety of sources, especially SSCR working group projects, in order to suggest answers to such questions as:
  - how can school science be made more pertinent to youngsters' thinking?
  - in what ways can we help young people to become confident users of science?
  - what is the role of technology studies in the secondary curriculum?

ISBN 0 435 54821 2

Also available:

Better Science: A Directory of Resources contains details of a broad range of materials produced by local working groups and the Review's Central Team. It includes descriptive and evaluative statements on each piece of material listed.

Better Science: Making it happen summarises, for a wide audience, the thinking of the Review and provides a guide to implementing balanced science for all pupils.

Heinemann Educational Books/Association for Science Education for the School Curriculum Development Committee

50

Better Science: Key proposals 1
Better Science: Choosing content 2
Better Science: **Making it relevant to young people** 3
Better Science: Approaches to teaching and learning 4
Better Science: How to plan and manage the curriculum 5
Better Science: For both girls and boys 6
Better Science: Working for a multicultural society 7
Better Science: For young people with special educational needs 8
Better Science: Health and science education 9
Better Science: Building primary–secondary links 10
Better Science: Assessing progress 11
Better Science: Learning how to teach it 12